GRAND TETON NATIONAL PARK,

WYOMING

WATER RESOURCES SCOPING REPORT

David N. Mott

Technical Report NPS/NRWRS/NRTR-98/__

WATER RESOURCES DIVISION

National Park Service - Department of the Interior
Fort Collins - Denver - Washington

United States Department of the Interior • National Park Service

The National Park Service Water Resources Division is responsible for providing water resources management policy and guidelines, planning, technical assistance, training, and operational support to units of the National Park System. Program areas include water rights, water resources planning, regulatory guidance and review, hydrology, water quality, watershed management, watershed studies, and aquatic ecology.

Technical Reports

The National Park Service disseminates the results of biological, physical, and social research through the Natural Resources Technical Report Series. Natural resources inventories and monitoring activities, scientific literature reviews, bibliographies, and proceedings of technical workshops and conferences are also disseminated through this series.

Copies of this report are available from the following:

National Park Service (970) 225-3500
Water Resources Division
1201 Oak Ridge Drive, Suite 250
Fort Collins, CO 80525

National Park Service (303) 969-2130
Technical Information Center
Denver Service Center
P.O. Box 25287
Denver, CO 80225-0287

GRAND TETON NATIONAL PARK,

WYOMING

WATER RESOURCES SCOPING REPORT

David N. Mott[1]

Technical Report NPS/NRWRS/NRTR-98/154

August, 1998

[1]Hydrologist, U.S. Department of the Interior, National Park Service, Buffalo National River, Harrison, Arkansas

United States Department of the Interior
National Park Service

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This report describes hydrologic and related physical processes in and around Grand Teton National Park, how these processes interact with biological resources, and issues potentially affecting water resources. The Snake River is the park's principal stream and its upper watershed is almost entirely within federal boundaries, which results in high quality water entering the park. The Public Law establishing Grand Teton National Park in 1950 added 304,385 acres to the existing National Park Service unit. Extensive water resource development had already occurred in the Jackson Hole area prior to this addition. These developments were protected by the enabling legislation, as were other rights, until they could be acquired by the National Park Service (NPS). Additionally, Wyoming water law protects external proprietors diverting water from streams within or adjoining National Park Service lands.

The Snake River cutthroat trout, the only trout native to the park and found exclusively in the Jackson Hole area, is of particular management concern. Protection and restoration of spawning and rearing habitat is critical to the proliferation of this endemic species. Safeguarding ground water resources is similarly vital because the park is dependent on local wells to supply public water to millions of visitors each year. Proper management and disposal of wastewater and hazardous materials are essential if the park's high quality water is to be maintained. Stream flow alterations resulting from the operation of Jackson Lake Dam continue to change the character of the Snake River channel and adjoining riparian landscape. Other factors, such as diversion structures, modify tributary habitats.

Specific issues discussed in this document include:

- WATER RIGHTS / IRRIGATION

  Both local and interstate water allocations affect streamflows within the park. Diversions and storage/release patterns change base and peak flows, sediment transport processes, physical habitat condition, and riparian, wetland and terrestrial landscapes. A number of legal uncertainties are associated with any attempt park managers might initiate to restore instream flow to Snake River tributaries: (1) the predominance of acquired lands in the Jackson Hole area and the uncertain legal status of acquired water rights, (2) the lack of precedence for assigning federally acquired water rights to the state for instream flow protection, (3) provisions of the State Instream Flow Law significantly restrict the amount of allocations which can be converted to instream flow, (4) conversion to instream flow can not impair other users, (5) the Wyoming Game and Fish Department would have to rule that conversion to instream flow would benefit the stream's fishery.

- ROAD AGGREGATE MINING

  Grand Teton National Park contains many miles of paved and unpaved roads that the NPS maintains in conjunction with the Federal Highway Administration and other agencies. Past gravel and sand borrowing activities have impacted wetlands and stream channels, and have even resulted in enforcement action by the Corps of Engineers and the Environmental Protection Agency, requiring the NPS and other parties to restore and mitigate the loss of wetlands and related values. The National Park Service, Federal Highway Administration, and U.S. Forest Service are currently evaluating the environmental implications of developing a borrow pit within the glacial outwash deposits near Spread Creek on U.S. Forest Service lands.

- HAZARDOUS MATERIALS AND WASTEWATER MANAGEMENT

  Grand Teton National Park relies on eighteen wells, most of which are completed in the alluvial aquifer of Jackson Hole. This aquifer is characterized by high permeability and is susceptible to contamination from surface sources. The park has developed a plan to manage hazardous materials and is currently evaluating wastewater lagoons and septic systems. Wastewater at visitor facilities is disposed through evaporation and percolation, and data collected through monitoring over the past twenty-five years are being assessed to determine if ground or surface water resources are being impacted. Grand Teton National Park is also cooperating with the NPS Water Resources Division and the U.S. Geological Survey to develop a wellhead protection program.

- OIL AND GAS DEVELOPMENT

  The U.S. Forest Service is developing a site-specific oil and gas leasing analysis for 369,000 acres adjacent to Grand Teton National Park. While these developments are outside the surface watershed or downstream of the park, karst hydrologic conditions identified in the proposed leasing units could allow interbasin transfer of ground water to carry contaminants to springs within the Snake River drainage.

- HYDROLOGIC MODIFICATIONS

  Jackson Lake Dam changed the streamflow regime, bedload transport processes, and channel dynamics within the Snake River. Issues associated with the dam include: fluctuating shoreline elevations in Jackson Lake; maintenance of instream base flows; attenuation of peak flows; and, altered riparian community structure and function.

Lake Surface Fluctuations: Prior to the construction of Jackson Lake Dam in 1906, the elevation of the surface of Jackson Lake was relatively constant. With the storage and release of millions of acre-feet of water for irrigation, the lake surface fluctuates seasonally, some years making lake access difficult and degrading the aesthetic appeal of the shoreline.

Base Flows: Past closures of, and reduced flows from, the Jackson Lake Dam resulted in decreased productivity in the downstream Snake River and mortality within the beaver population. Recognition of the value of the Snake River fishery by the Bureau of Reclamation, and efforts of the Wyoming Game and Fish Department, have resulted in acceptable base flows being established for the Snake River.

Peak Flows: Historic stream gauge records show a decrease in the frequency and magnitude of peak flows as a result of the operation of Jackson Lake Dam. Thus, the Snake River below Jackson Lake Dam has insufficient competence to transport its bedload within reaches below major sediment sources such as tributaries and terrace cutbanks. As a result, greater braiding and meandering is observed in reaches below sediment sources, while above and below these reaches the Snake River is characterized by greater horizontal stability.

Riparian Vegetation: Riparian vegetation along the Snake River below Jackson Lake Dam has also responded to streamflow alterations. Horizontal channel stability has shown a net increase and has resulted in an increase in the spatial distribution of forested climax communities, at the expense of willow-alder shrub swampland. A decline in channel avulsions in stabilized reaches has also eliminated numerous side channels which served as spawning and rearing habitat for the Snake River cutthroat trout.

- LIVESTOCK AND UNGULATE GRAZING

Researchers studying riparian vegetative communities noted that changes could not be explained by hydrologic modifications alone. Grazing by cattle, elk, antelope, and bison are selectively impacting the park's deciduous woody species and accelerating the successional progression toward Engelmann spruce. Cattle and horse access to small streams, as well as overpopulation of wild ungulates, can also elevate sediment, bacterial and nutrient loads in these streams and reduce stream bank strength due to trampling and overgrazing, ultimately changing stream width/depth ratios and fluvial habitats.

- FISH STOCKING

Stocking programs can result in interspecific competition with native species and introduction of diseases or pathogens to the aquatic environment. As a result of past stocking, four nonnative salmonids inhabit the upper Snake River drainage. Since 1929, the Wyoming Game and Fish Department has stocked hatchery fish almost every year in one or more waters within the park. Other than in Jackson Lake where lake trout are stocked, only hatchery reared cutthroat trout or their eggs have been stocked within the park since 1966. The Wyoming Game and Fish Department claims sole jurisdiction over fishery management and has resisted attempts by the National Park Service to influence fisheries programs.

- FISHERIES RESTORATION / ENHANCEMENT

Protection and restoration of Snake River cutthroat trout spawning habitat is recognized as vital by both the Wyoming Game and Fish Department and the National Park Service. The two agencies have cooperated in the past to remove dams, restore stream habitat, and renovate spawning gravel on impacted tributaries. Grand Teton National Park staff is uncertain if elements of current Wyoming Game and Fish Department proposals for instream work should be interpreted as enhancement.

- FLOOD PLAIN MANAGEMENT

The construction of Grand Teton National Park facilities within flood plains, such as the headquarters at Moose, bridges, streamside campgrounds, boat accesses, and irrigation headgates, demands a level of stability not naturally present in the region's water courses. Therefore, efforts are required to increase the stability of some stream reaches, necessitating significant commitments of manpower and interfering with natural stream and riparian processes.

Levees: From 1957 to 1964, the U.S. Army Corps of Engineers constructed 11,600 feet of flood control levees along the lower reaches of the Snake River (south of Moose Bridge) within Grand Teton National Park. Stream energy was subsequently concentrated within these levees resulting in a lowering of the channel bed elevation, destruction of vegetated islands, and the near elimination of trout habitat. Additional levees are maintained by the Bureau of Reclamation along Pilgrim Creek, but their necessity is currently being evaluated. Removal of the Pilgrim Creek levees, while restoring natural stream functions, could impact the Teton Park Road, the Willow Flats area, Oxbow Bend, and Spring Creek (a spawning area for cutthroat trout).

Bridges: The high rate of aggradation and lateral migration exhibited by many of Grand Teton National Park's streams are continuously working against efforts to confine these streams to discrete, unmovable bridge openings. As a result, armoring and maintenance are often required to protect roads and bridges, which interferes with natural stream functions and degrades physical habitats and aesthetic values.

River Access Maintenance: Gravel dredging is routinely used to provide better boating access to the Snake River. More recent management has incorporated riprapping where erosion is a perceived problem. Because of the value of the Snake River corridor as a relatively intact natural area, Grand Teton National Park must ensure invasive management such as riprap and dredging are well justified, and that all other alternatives are properly evaluated.

Flood Plain Developments: The National Park Service has constructed infrastructure within 100-year flood plains of the Snake River and tributaries, most notably the headquarters and maintenance facilities at Moose. These facilities are potentially threatened by stream bank erosion and flooding. A comprehensive evaluation of flood hazards and stabilization techniques is required.

- RECREATION

  Recreational activities such as camping, hiking, floating, snowmobiling and horseback riding can result in detectable water quality degradation in heavily used areas. Because back-country users often utilize raw water for drinking purposes, and to protect the pristine nature of park waters, water quality monitoring is being conducted and mitigation measures implemented, as appropriate, in heavily used areas.

The Water Resources Division of the National Park Service is responding to many of the water resource concerns identified in this report by providing funding and technical advice. These programs and other activities are described in the Staffing and Ongoing Programs section.

RECOMMENDATIONS

Issue specific recommendations are withheld due to the complex nature of the park's physical, biological, and political environments, and the relatively short time allotted to the scoping effort. Only very thorough, site-specific knowledge of the region's complex hydrologic and biologic processes, applicable laws, National Park Service mandates, park management concerns and constraints, local, state, and federal agency relationships, legislative history, and a myriad of other factors, will allow specific recommendations to be legitimately put forth. It is therefore recommended that a more detailed Water Resource Management Plan be developed which identifies water resource issues, needs, and priorities in much greater detail. Issue specific recommendations would then be developed in coordination with other agencies and interested parties, and enunciated through project statements to be incorporated in the park's Resource Management Plan. Furthermore, in recognition of the complexities involved in coordinating, developing, and implementing a Water Resources Management Plan, it is strongly recommended that a water resource professional staffed at Grand Teton National Park be the lead author. The planning process would leave the author well positioned to leverage internal and external funds and work effectively with park managers, other agencies, and local interests to implement recommended projects.

INTRODUCTION

Grand Teton National Park contains some of the most diverse water resources of any unit in the National Park System: from alpine lakes to semi-arid riparian zones, from kettle ponds to the 25,540 acre Jackson Lake, and from mountain springs issuing from karst aquifers to thermal springs arising from thousands of feet below the surface. Surface water resources cover over ten percent of the park, and ground water resources are far more plentiful. The Snake River, the principal stream draining the park and surrounding watershed, is heavily effected by downstream water development. The relatively natural state of this stream within the park is significant in a region dominated by dams and diversions.

Five mainstem reservoirs in Wyoming and Idaho divert nearly all streamflow from the Snake River for irrigation. Jackson Lake Dam, within Grand Teton National Park, is uppermost in this system. Reservoir operations have affected aquatic habitat and biota to varying degrees since dam construction in 1906. Local diversions to supply water for irrigated agriculture, and in more recent times, residential and commercial diversions, impact tributaries above and within the park.

The water resource issues discussed in this document include:

- water rights/irrigation
- road aggregate mining
- hazardous materials and wastewater management
- oil and gas development
- hydrologic modifications
- livestock and ungulate grazing
- fish stocking
- fisheries restoration/enhancement
- flood plain management
- recreation

The purpose of this Water Resources Scoping Report is to summarize the existing information about the water resources of Grand Teton National Park and to determine and briefly evaluate water resource issues within the park. Specific recommendations regarding most of the issues are withheld due to the complex nature of the park's physical, biological, and political environments, and the relatively short time allotted to the scoping effort. Given this, the author strongly recommends a more detailed and comprehensive water resources management plan be developed and that it be prepared by a water resource specialist staffed at Grand Teton National Park.

EXISTING RESOURCE CONDITION

Water is often a significant resource in units of the National Park Service (NPS), either through support of natural systems or provision for visitor use. The NPS seeks to perpetuate surface and ground water as integral ecosystem components by carefully managing the consumptive use of water and striving to maintain the quality and health of aquatic ecosystems in accordance with all applicable laws and regulations. Water resource inventories and monitoring are, therefore, essential activities of park resource management.

This Water Resources Scoping Report summarizes existing water resources information and identifies and discusses a number of water related issues and management concerns pertinent to Grand Teton National Park and John D. Rockefeller, Jr., Memorial Parkway (administered jointly and referred to throughout this document as Grand Teton National Park). It provides information required by the Water Resources Division of the NPS to determine if a water resources management plan is needed for this park. Additionally, the summary of water related issues can assist with park resource management and be incorporated into the park's resource management plan.

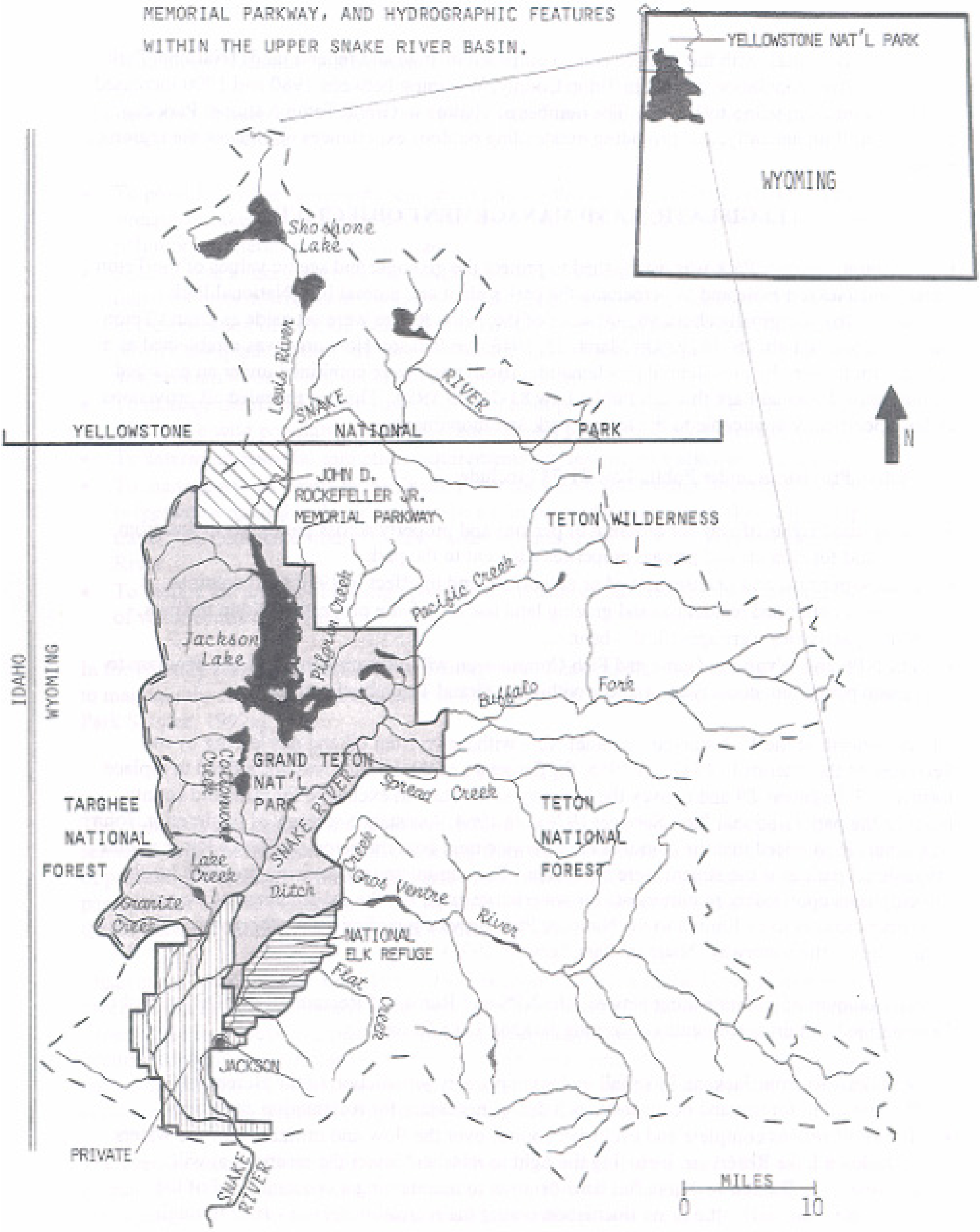
LOCATION AND LANDOWNERSHIP

Grand Teton National Park and John D. Rockefeller, Jr., Memorial Parkway are located in Teton County in the northwestern corner of Wyoming (Figure 1). The two areas are administered jointly from the park headquarters in Moose, Wyoming, forming a NPS unit about 38 miles long and 22 miles across, containing 485 mi^2. The west boundary is the crest of the Teton Range and adjoins U.S Forest Service lands comprising the Targhee National Forest. The south boundary is near the confluence of the Gros Ventre and Snake rivers, just north of the town of Jackson, and is conterminous with private lands and the Fish and Wildlife Service's National Elk Refuge. The east boundary abuts the Bridger-Teton National Forest, while Yellowstone National Park forms the north boundary.

Grand Teton National Park, together with Yellowstone National Park, comprises part of a vast upland reserve, which is held almost exclusively in federal ownership. Above Moose, the Snake River watershed is entirely within federally authorized boundaries (National Park Service, 1976). The U.S. Forest Service manages about 2,275,200 acres (70.3%) in Wyoming's portion of the Snake River basin, in the Bridger-Teton and Targhee National Forests; the NPS manages about 686,100 acres (21.21%); private land accounts for 227,100 acres (7.05%); the National Elk Refuge is managed by the U.S. Fish and Wildlife Service and encompasses 24,600 acres (0.76%); the Bureau of Land Management administers about 13,000 acres (0.4%); while the state owns about 9,000 acres (.28%) (Wyoming State Engineer's Office, 1972).

Of the 310,385 acres included as part of Grand Teton National Park in 1950, 14,027 acres were privately owned. In the 1976 land-use study, the statistics for the park showed: 304,748 federal, 1,366 state, and 4,329 private acres. For Teton County, private lands total 71,611 acres of

FIGURE 1: LOCATION OF GRAND TETON NATIONAL PARK AND JOHN D. ROCKEFELLER JR. MEMORIAL PARKWAY, AND HYDROGRAPHIC FEATURES WITHIN THE UPPER SNAKE RIVER BASIN.



MAP COMPILED BY MIKE NARANJO FROM: NOLAN AND MILLER, 1995

WYOMING STATE ENGINEERS OFFICE, 1972

1,814,820 acres total, with the balance being composed of state and federal lands (National Park Service, 1976). Population growth in Teton County, Wyoming between 1980 and 1990 increased by 19 percent from 9,355 to 11,172. The number of visitors to Grand Teton National Park can exceed 4 million annually, and providing outstanding outdoor experiences dominates the region's economy.

LEGISLATION AND MANAGEMENT OBJECTIVES

Grand Teton National Park was established to protect the geologic and scenic values of the Teton Range and Jackson Hole and to perpetuate the park's plant and animal life (National Park Service, 1976). Originally about 96,000 acres of the Teton Range were set aside as Grand Teton National Park on Feb. 26, 1929. On March 15, 1943, the Jackson Hole area was established as a national monument by presidential proclamation. Both units were combined under an enlarged Grand Teton National Park through Public Law 81-787 in 1950. This act repealed all provisions of law specifically applicable to the former park and monument.

Legislative Provisions under Public Law 81-787 include:

- Designated rights of way for crossing of persons and property across parklands to and from state and forestlands and private properties adjacent to the park.
- Leases, permits, and licenses issued or authorized and in effect in 1950 shall continue.
- Allowed continued residential and grazing land use on private properties within the park.
- Mining activities were specifically banned.
- The NPS and Wyoming Game and Fish Commission will cooperate to develop a program to ensure permanent conservation of elk within the Grand Teton National Park.

All lands north of the 11th standard parallel were withdrawn from oil and gas leasing by the Secretary of the Interior in 1947. In 1955, the Secretary of the Interior was authorized to replace former U.S. Highway 89 and convey the highway to the state in exchange for state and county roads in the park (National Park Service, 1976). In 1964, Assistant Secretary of the Interior, John A. Carver, Jr., advised that the National Park Service treat boat traffic on the Snake River within the national park as if the stream were navigable. The administrative decision provides for the full emphasis upon safety requirements for waterborne craft, but the management of the river float operations is to be limited to the National Park Service jurisdictional authority over the land to the edge of the waterway (National Park Service, 1995).

A memorandum of understanding between the NPS and Bureau of Reclamation (BOR) signed in 1956 defined certain agreements concerning Jackson Lake Reservoir:

- Withdrawals from Jackson Lake fall under the primary jurisdiction of the Bureau of Reclamation, for use and occupancy, as it deems necessary for reclamation activities.
- The BOR retains complete and exclusive control over the flow and utilization of the waters of Jackson Lake Reservoir, including the right to raise and lower the reservoir at will. However, the Bureau will give full consideration to maintaining a constant level of the operating pool, with little or no fluctuation during the recreation season - June through

September (National Park Service, 1995).

Management objectives defined in the 1976 Master Plan (National Park Service, 1976) related to water resources include:

- To provide sewage treatment facilities to prevent the discharge of any effluent directly into streams or lakes, as well as to avoid the disruption of the area's ecosystems through the pollution or alteration of ground water.
- Seek to give a lake rather than reservoir quality to Jackson Lake, without causing serious impairment to downstream resources. To develop procedures, in cooperation with the BOR, in the operation of Jackson Lake Dam to ensure water flows on the Snake River sufficient to provide adequate aquatic environment for the native fishes, and protection of resources downstream through installation of a bypass facility.
- To manage the native Snake River cutthroat trout population so as to ensure the perpetuation of a native wild population within its range as part of a natural ecosystem.
- To determine essential sanitation requirements for designated backcountry campsites.
- To manage access points to the Snake River for scenic and fishing float trips, so as to perpetuate a natural and wilderness-type environment through which float-trip groups can travel. To undertake studies to determine the capacity of visitor use on and along the Snake River.
- To reduce the impact of fishing upon aquatic resources, and reduce the unnatural influences of water control activities.

In the recently completed Snake River Management Plan, public opinion emphasized the desire to maintain the river's natural character in order to protect wildlife and scenic values (National Park Service, 1997a).

CLIMATE

The climate is best described as cold with humid winters; however, the valleys are actually semiarid, with the moisture deficit occurring from mid-June until fall. The park is in the latitude of prevailing westerlees with a dominance of Maritime Pacific air. This air has been modified by passage over several mountain ranges which have relieved most of the low-level moisture from the air mass (Wyoming State Engineer's Office, 1972).

Mean annual precipitation from 1951 - 1980 is about 60 inches in the Teton Range; whereas, precipitation in Jackson Hole is about 16 - 20 inches (Martner, 1986). Although mountains and valleys influence local precipitation amounts, precipitation generally increases with elevation and occurs mainly as snow during the winter, rain and snow during the spring and fall, and rain during the summer. Precipitation is greatest in winter and spring resulting in a snowpack commonly reaching depths of five feet by spring (Cox, 1974).

The average annual air temperature is 34.7 ^{o}F near Moran (Figure 2) and 38 ^{o}F at Jackson. At Moran, the mean monthly temperature ranges from 13.0 ^{o}F in January to 59.2 ^{o}F in July (Nolan and Miller, 1995). During most years, maximum temperatures are near 90 ^{o}F and minimum

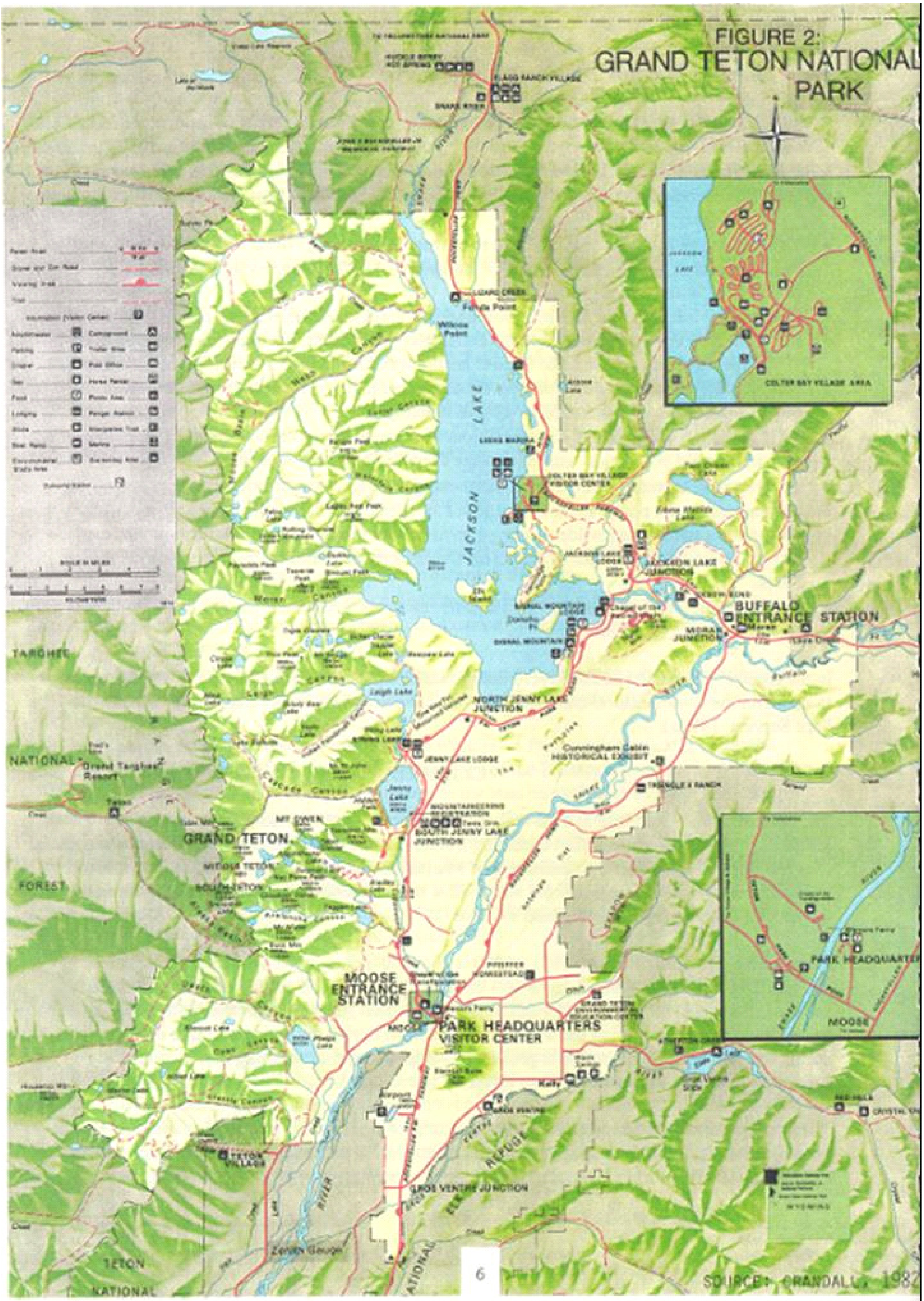


FIGURE 2:
GRAND TETON NATIONAL
PARK
JACKSON LAKE
BUFFALO ENTRANCE STATION
MORAN JUNCTION
JACKSON LAKE JUNCTION
NORTH JENNY LAKE JUNCTION
Cunningham Cabin HISTORICAL EXHIBIT
SOUTH JENNY LAKE JUNCTION
MT OWEN
GRAND TETON
MOOSE ENTRANCE STATION
PARK HEADQUARTERS VISITOR CENTER
PARK HEADQUARTERS
MOOSE
COLTER BAY VILLAGE AREA
GROS VENTRE JUNCTION
TARGHEE
NATIONAL
FOREST
TETON
NATIONAL
Grand Targhee Resort
Leigh Lake
Jenny Lake
SOURCE: CRANDALL, 1982

temperatures are less than -30 ^oF. Relative humidity ranges from 65 - 75 percent during the winter to 35 - 45 percent during the summer (Cox, 1974).

WATERSHED PHYSIOGRAPHY

Grand Teton National Park is entirely contained within the Snake River basin. Approximately 5,136 mi^2 in western Wyoming are drained by the Snake River, the only basin in Wyoming providing water to the Columbia River (Wyoming State Engineer's Office, 1972). The Snake is one of the smallest major drainages in the state, yet it carries the largest average volume of any of the Wyoming rivers (Kiefling, 1978). The drainage area above Jackson Lake is approximately 820 mi^2, much of which comes from Yellowstone National Park (Miller and Dustin, 1997). Many perennial streams flow from nearby mountains across Jackson Hole to the Snake River (Figure 2). Principal tributaries of the Snake River within the park are Pilgrim, Pacific, and Spread Creeks, Buffalo Fork and Gros Ventre River from the east and Cottonwood Creek from the west (Cox, 1974; Mekeel, 1972).

Most of Grand Teton National Park is within Jackson Hole and the Teton Range (Figure 1). Jackson Hole is part of the Snake River valley and trends northeast-southwest. It is surrounded by mountains or upland areas and extends from Jackson Lake to about six miles south of Jackson, and is 48 miles long and six to eight miles wide. The valley is bordered on the west by the Teton Range and on the east by less prominent uplands. Jackson Hole slopes south from about 7,000 feet near Jackson Lake to about 6,000 feet at the south end of the valley. Stream channels, terraces, ridges, and depressions break the regularity of the valley floor. The lowest point in the park coincides with the exit of the Snake River from the south park boundary at 6,320 feet, while the highest point is Grand Teton at an elevation of 13,770 feet (Cox, 1974).

The Teton Range rises approximately 7,000 feet above the sagebrush flats of Jackson Hole and contains the youngest mountains in the Rocky Mountain chain. The absence of foothills highlights the contrast between the valley and the Teton Range. East of Jackson Hole are the Gros Ventre Mountains, composed of folded sedimentary rocks. Distinctive features in the area include alpine peaks, lakes, glaciers and snowfields. Alpine lakes are numerous, and in a line along the foot of the Teton Range, are seven valley lakes. A concentration of depressions (kettle lakes) between the southeast end of Jackson Lake and the Snake River is responsible for this area being named "The Potholes" (Wyoming State Engineer's Office, 1972).

The source of the Snake River is on the Two Ocean Plateau on the southwestern slope of the Continental Divide in Yellowstone National Park. The river flows westward in Yellowstone National Park, then turns southward to enter Jackson Lake. Due to ongoing movement along the Teton Fault and the concomitant westward tilting of Jackson Hole, the Snake River is not always in the lowest part of its valley. For example, near the town of Wilson, Fish Creek is 15 feet lower than the Snake, but with a gentler gradient runs parallel to the river and joins it near the southern end of Jackson Hole (Wyoming State Engineer's Office, 1972). A coniferous forest has developed on the mountain slopes and glacial moraines in the vicinity of Jackson Hole, while sagebrush dominates the highly permeable valley floor. Aspen stands still occur in upland areas, but may exhibit declining vitality as a result of the long history of fire suppression. Riparian areas contain cottonwood, willow, and spruce along the meandering courses of the Snake River and its tributaries (National Park Service, 1976).

GEOLOGY

Geologic structures in Grand Teton National Park are located within the Middle Rocky Mountain physiographic province and result from tectonic activities associated with the Laramide orogeny and continuing through recent times. In the southern Yellowstone area, the high-altitude Two Ocean Plateau was created by rhyolite flows of Quaternary age (Love and Reed, 1968; Love and Christiansen, 1985).

The Washakie and Absaroka ranges are located northeast of the park and consist of thrust-faulted, asymmetric anticlines and andesitic volcaniclastic rocks, respectively. The Pinyon Peak and Mount Leidy Highlands, east of the park, include conglomerates of late Cretaceous and early Tertiary age. The Gros Ventre Range, located southeast of the park, is composed of thrust faulted sedimentary rocks of Mesozoic and Paleozoic age, including carboniferous units which form karst. The Teton Range is an upthrown, tilted fault-block that contains more than 5,000 feet of Paleozoic sedimentary strata including significant deposits of karst forming limestones and dolomites. Jackson Hole is a structural basin as much as 3.1 miles deep formed by a tilted, downthrown fault block hinged to the east (Nolan and Miller, 1995).

Rocks ranging in age from Precambrian to Quaternary crop out in and near Grand Teton National Park. The Teton Range consists of a core of igneous and metamorphic Precambrian rocks overlain in most of the range by westward dipping sedimentary Paleozoic rocks. Jackson Hole contains mostly Quaternary glacial, lacustrine, and alluvial deposits underlain by Tertiary volcanics and older rocks, forming a sequence as much as 4,000 - 7,000 feet thick. The uplands east of Jackson Hole are underlain by Precambrian through Cenozoic rock strata (Cox, 1974; Nolan and Miller, 1995).

Alluvium occurs as flood plain deposits and alluvial fans in valleys, and commonly consists of well-sorted beds of silt, sand, and gravel. Much of the alluvium is glacial-outwash material that has been reworked by modern streams and greatly resembles the parent material. Alluvial fans have formed along the margins of Jackson Hole where streams enter the valley from surrounding uplands. Relatively large amounts of ground water occur within the alluvium of the park (Cox, 1974).

Faults have greatly altered the continuity of rock units in and near the park. Vertical displacement along the Teton Fault is as much as 23,000 feet (4.4 miles). Faults are also present east and south of Jackson Hole, but are obscured by glacial and alluvial deposits in Jackson Hole (Cox, 1974). Jackson Hole and the bordering Tetons are both tilted blocks of the earth's crust. The block forming the Tetons was uplifted on its east side, while the block forming Jackson Hole was down dropped on its west side. These blocks are joined at the Teton Fault, and the floor of Jackson Hole tilts westward toward the Tetons. Relative movement along the fault is estimated to average about 1 foot per 300 - 400 years. As tilting of the block continues, the Snake River seeks the lowest portion of the valley by migrating westward. Flood-control levees, within and south of the park, inhibit this natural migration (Love and Reed, 1968).

Jackson Hole has been glaciated at least three times, with the oldest event being the most widespread. The ice in many places exceeded 2,000 feet in thickness, and later glacial events eroded or covered parts of earlier ones (Love and Reed, 1968). During the latest glacial stage, ice flowed down canyons in the Teton Range onto the floor of Jackson Hole and built the moraines that dam Jackson, Leigh, Jenny, Bradley, Taggart, and Phelps lakes. The glacial deposits are generally either morainal or outwash deposits consistent with alpine glaciation. Morainal deposits are commonly ridges or hills that were formed by material deposited directly by glaciers as the ice melted. Outwash deposits form plains where material carried by streams, that flowed from the melting glaciers, was deposited. Outwash deposits are more permeable and yield water more easily to wells than morainal deposits. Wells yielding 1,000 gpm can be completed in the outwash deposits of Jackson Hole. Morainal deposits contain more clay and silt than outwash deposits resulting in better retention of soil moisture and nutrients. Consequently, moraines are heavily forested, while outwash plains are covered by sagebrush (Cox, 1974).

Lacustrine deposits in and near the park occur where lakes existed before, during, or after glaciation. Landslide deposits also occur, most extensively in the upland areas east and northeast of Jackson Hole (Cox, 1974). The Gros Ventre drainage is characterized by sedimentary terrain in which numerous landslides have occurred. The mass wasting contributes large volumes of bedload to streams draining from the east (Wyoming State Engineer's Office, 1972).

SOILS

The variety of soils found in the area result from the kinds and origins of the parent materials as well as variations in climatic conditions. There are three predominant soil types, the most widespread of which is a loamy to loamy-skeletal mixed soil found from 6,000 to 12,500 feet on low mountains, fans, and uplands. Generally, these soils are less than ten inches in depth, well drained, and have a medium available water holding capacity. Major problems on these soils are erosion and climatic limitations, and recommended land treatment measures are forest or rangeland with good irrigation practices (Wyoming State Engineer's Office, 1972).

Steep mountains, with elevations between 6,800 and 14,000 feet, have soils classified as loamy-skeletal and mixed and range from 10 - 60 inches in depth. They are well to poorly drained, and have a low to medium water-holding capacity. Major soil problems are cold climate and steep slopes, and the recommended land treatment is continued forestland management (Wyoming State Engineer's Office, 1972).

Most of the cropland in the basin is found on fans, rolling hills, and bottomland at elevations of 6,000 to 6,800 feet. Low average annual precipitation at these elevations dictates irrigation for most crops, and a freeze-free season from 0-50 days limits crop production to grass, hay, and some small grain. Soils in this area consist of fine to course loams, and fine to course silts and mixes, and range from 17 - 60 inches in depth. These soils vary from poorly to well drained, with low to high available moisture holding capacities. Major soil problems are water erosion, wetness, and sensitivity to drought. Recommended land treatment measures are residue management, cross-slope operations, cropping sequence, drainage where necessary, and range management (Wyoming State Engineer's Office, 1972).

AQUATIC FAUNA

The aquatic invertebrate fauna of Grand Teton National Park includes 170 identified species. Invertebrate species diversity is lower in the Snake River between Jackson Lake Dam and Pacific Creek than in areas downstream. Kroger (1967) showed that 23 major invertebrate species were identified in downstream areas; whereas, only seven identified species exist between the dam and Pacific Creek. This may reflect fluctuating flow from the dam operation, differences in substrate, and lack of niche diversity above Pacific Creek (Good, 1971).

The fish fauna is typical of intermountain cold waters and is relatively species-poor (twelve native and seven introduced species) (National Park Service, 1986). The native fish fauna includes Snake River cutthroat trout (*Salmo clarki spp*.), mountain whitefish (*Prosopium williamsoni*), Utah sucker (*Catostomus ardens*), bluehead sucker (*C. discobolus*), mountain sucker (*Pantosteus platyrhynchus*), Bonneville redside shiner (*Richardsonius balteatus*), speckled dace (*Rhinichthys osculus*), longnose dace (*R. cataractea*), Utah chub (*Gila atraria*), leatherside chub (*G. copei*), mottled sculpin (*Cottus bairdi*), and the Paiute sculpin (*C. beldingi*) (Kiefling, 1978). The Snake River cutthroat trout, the only native trout in the park, is part of a morphologically distinct group (possibly a race) of cutthroat trout found only in the Snake River in the Jackson Hole area. A relic population of leatherside chub (one of the minnows) exists in the Snake River near the mouth of the Buffalo Fork River, the only known population of this species in the Snake River drainage. Four introduced trout species presently inhabit portions of the upper Snake River drainage in the park: lake, brown, brook, and rainbow (National Park Service, 1986).

Excepting fish, aquatic life on federal land within the park is protected from consumptive use. Consumptive use of fish is carried out under Wyoming regulations and fisheries management programs. Some originally barren, high alpine lakes have been artificially stocked with native and nonnative species of fish. At least six previously barren lakes in the Teton Range now contain cutthroat trout populations from former stocking programs. The park's major fisheries are Jackson Lake and the Snake River downstream from the lake. Jenny, Leigh, and Phelps Lakes are also important. Most other waters receive little fishing pressure. With the exception of Jackson Lake, only cutthroat trout or their eggs have been stocked in the park since 1966 (National Park Service, 1986).

The Snake River cutthroat trout (*Salmo clarki spp*) inhabits the river between Jackson Lake and Palisades Reservoir. The population supports an important fishery and is of considerable scientific and aesthetic value. The reach between the Jackson Lake Dam and Pacific Creek has the most deep water habitat and this trophy fishery produces Snake River cutthroat trout commonly weighing up to seven pounds (U.S. Bureau of Reclamation and National Park Service, 1984). The Snake River cutthroat trout is thought to be a separate subspecies of the cutthroat series due to its distinct fine spotting pattern and the fact that it is well adapted to large swift streams (Kiefling, 1978). Other factors defining it as a separate subspecies are that it is fast growing but short lived, and has a high rate of natural mortality. In fact, only one pair of spawners returns for every 2,000 eggs laid (Wyoming Game and Fish Department, 1992).

During spring spawning, Snake River cutthroats migrate into tributaries. The major surface drainages, such as Pilgrim Creek and the Gros Ventre River, provide limited habitat for permanent and spawning fish. Scouring during high flows, sedimentation, ice formation, lack of instream habitat during high and low flows, and poor food production limit the resident fish populations of these streams. Spring fed tributaries provide better spawning and rearing habitat because of their more consistent flows, gravel substrate, and related attributes (U.S. Bureau of Reclamation and National Park Service, 1984). Since many of the nursery streams are spring fed, spawning may continue through June. The young exhibit downstream migratory behavior and generally move into the Snake River as yearlings (Kiefling, 1978). Spawning success depends highly upon the conditions of these tributaries, which are easily affected by migratory blocks (beaver dams, natural cascades, and irrigation headgates), lack of cover, substrate size, turbidity, flooding, pollution from livestock, and lack of food production (National Park Service, 1997a).

Additional concerns regarding the future of the Snake River cutthroat trout were identified by Rowan (1992), and include water development, irrigation water demands, loss of aquatic habitat from flood control management, and fishing. Population abundance has declined in many waters chiefly as a result of the introduction of exotic lake trout, and angling pressure. In particular, some spawning streams have been heavily impacted by past irrigation diversion practices (National Park Service, 1986).

Stock density information supports the thesis that cutthroat trout densities in the river fluctuate from year to year in relation to the volume of discharge from Jackson Lake Dam. In general, fishing does have a detectable effect on the stock, but Kiefing (1978) concluded regulations are adequate to result in fish harvests that stimulate the rate of recruitment. Studies of the cutthroat trout suggest that offshoots of the main river are also used as a rearing area. Since spring runs serve as the major spawning areas, their condition may influence year class strength as much as any other factor (U.S. Department of Agriculture, 1982).

RARE AND ENDANGERED SPECIES

No fish species in park waters are listed as threatened or endangered (U.S. Bureau of Reclamation and National Park Service, 1984). However, all five endangered or threatened species federally listed for this area have used the Snake River corridor: the endangered peregrine falcon (*Falco perigrinus)* and whooping crane (*Gus americana)*, and the threatened bald eagle (*Haliaeetus leucocephalus)*, grizzly bear (*Ursus arctos horriblis)*, and gray wolf (*Canis lupus)*. As of November 1994, all wolves within Wyoming are regarded as part of the nonessential experimental wolf population. On National Park and National Wildlife Refuge system lands, wolves are still considered a threatened species and are fully protected under Section 7(c) of the Endangered Species Act (U. S. Fish and Wildlife Service, 1995; National Park Service, 1997a).

Peregrine falcons nest in and migrate through the park, but no peregrine nests have been located in the Snake River corridor. Park files contain 33 documented sightings of peregrine falcons in riparian and upland areas of the river, indicating use of the area for travelling and foraging. Twelve documented sightings of whooping cranes have also been reported from the Snake River corridor. Bald eagles use the Snake River corridor throughout the year and six bald eagle pairs currently nest, roost, and loaf along the river corridor. Wyoming Game and Fish Department (WGFD) tracking data indicate at least three different grizzly bears used the Snake River corridor in 1994 and 1995. In the past 20 years, there have been no verified sightings of the gray wolf in the Snake River corridor (National Park Service, 1997a).

The U.S. Fish and Wildlife Service has also identified the following fourteen candidate species (category 2) which may occur within the Snake River corridor (National Park Service, 1997a).

Preble's shrew [*Sorex preblei*]
Spotted bat [*Euderma maculatum*]
North American wolverine [*Gulo gulo luscus*]
North American Lynx [*Felix lynx canadensis*]
Trumpeter swan [*Cygnus buccinator*]
Harlequin duck [*Histrioicus histrionicus*]
Northern goshawk [*Accipiter gentilis*]
Loggerhead shrike [*Lanius ludovicianus*]
Western boreal toad [*Bufo boreas*]
Spotted frog [*Rana pretiosa*]
Leatherside chub [*Gila copei*]
Jackson Lake Springsnail [*Pyrgulopsis (Fontelicella or Amnicola) robusta*]
Jackson Lake Snail [*Helisoma (Carinifex) jacksonense*]
Payson's bladderpod [*Lesquerella paysonii*]

WATER RESOURCES

The surface water resources of the Snake River basin are utilized for agricultural, municipal, and industrial water supplies, fish and wildlife habitat, hunting, fishing, boating, and other water-based recreation (Wyoming State Engineer's Office, 1972). Water resource development, stream alterations, irrigated agriculture, grazing, aquaculture, and species introduction have affected stream biota in the upper Snake River basin. Water development in the basin is extensive, resulting in nearly all of the Snake River's flow being diverted for irrigation at Milner Dam in Idaho (Maret, 1995a). Surface water supplies about 94 percent of the total offstream use in Teton County, with irrigation accounting for nearly 100 percent of this use (Nolan and Miller, 1995).

Cox (1974) reported public water supplies in the park utilize both surface and ground water. Current public health requirements state that only ground water, if adequate in quantity and quality, be used for water supplies in areas of heavy use. Water is used within the park for public water supplies at NPS facilities, for commercial and domestic use at guest ranches and private residences, and for irrigation. The park's water resources include tarn lakes, glacial outflows, tumbling streams, lakes formed behind glacial moraines, and ground water aquifers that maintain spring and stream flow (National Park Service, 1976). These water resources are an integral component of all aspects of the park's natural environment.

Surface Water

Approximately 10 percent (31,000 acres) of Grand Teton National Park is covered by surface water. Most of this lies within six piedmont lakes along the eastern front of the Teton Range, of which Jackson Lake is the largest (25,540 acres at full pool). About 100 alpine lakes (varying from 1 to 60 acres) are within the Teton Range, most above 9,000 feet. Seven streams, originating in the Teton Range, drain eastward into Jackson Lake; six others drain into Cottonwood Creek and then the Snake River near Moose; and, three drain the southern portion of the Teton Range into Lake and Fish creeks, which flow into the Snake River south of the park. Eight major streams drain highlands in the Bridger-Teton National Forest north and east of the park and flow into Jackson Lake or the Snake River within the park. Approximately 75 pothole ponds of less than 0.5 acres to more than 35 acres occur in the glacial drift area south and east of Jackson Lake. Two large lakes, Two Oceans and Emma Matilda, were not glaciated during the last advance of ice and the origin of their basins is unknown (National Park Service, 1986).

Many springs emerge along the Snake River flood plain south of the Buffalo Fork confluence. Numerous springs also issue from limestone areas in the northwest and southwest portions of the park. Other springs are located along the park's east boundary and include several thermal springs. Thermal springs also occur on the west side of Jackson Lake and may be associated with the Teton Fault (National Park Service, 1986).

Flow measurements recorded on the Snake River by the U.S. Geological Survey (USGS) at Moran, Wyoming, based on a 76 year record are: average annual flow = 1,439 cubic feet/second (cfs); record high = 15,100 cfs (06/1918); record low = 0.3 cfs (10/1970) (U.S. Bureau of Reclamation and National Park Service, 1984). In all, stream flow is routinely measured at five locations within or immediately adjacent to the park (Table 1) (Nolan and Miller, 1995).

An interagency agreement signed between the National Park Service and the U.S. Geological Survey in 1995 called for the installation and monitoring of five stream gauges near the south boundaries of Grand Teton National Park. The gauges are intended to provide time-series information concerning the surface elevation and flow of the river, tributaries, and diversions at the following locations (National Park Service and U. S. Geological Survey, 1995):

Granite Creek Supplemental above Lake Creek near Moose
Lake Creek below Granite Creek Supplemental near Moose
Granite Creek Supplemental below Lake Creek near Moose
Granite Creek above Granite Creek supplemental near Moose
Snake River near the Moose bridge

TABLE 1: Selected streamflow-gaging stations and records of peak and mean discharges in the vicinity of Grand Teton National Park.

[Site number: simplified site number used in this report to identify location of streamflow-gaging stations. Station number: assigned by U.S. Geological Survey to locations where streams are regularly measured or sampled. The first two digits identify the major basin in which the station is located. The remaining six digits identify the relative location. mi^2, square miles; ft^3/s, cubic feet per second]

Site number (pl. 2)	Station number	Station name	Drainage basin area (mi^2)	Period of record: Daily or monthly discharge (calendar years)	Period of record: Instantaneous annual peak discharge (water years)	Instantaneous peak discharge for period of record: Date	Instantaneous peak discharge for period of record: Discharge (ft^3/s)	Mean discharge for period of record (ft^3/s)
1	13010065	Snake River above Jackson Lake, at Flagg Ranch	486	1987-present	1984-92	5/31/84	11,000	803
2	13011000	Snake River near Moran	807	1903-present	1904-67; 1971-92	6/12/18	15,100	1,438
3	13011500	Pacific Creek at Moran	169	1906; 1917-18; 1944-75; 1978-present	1918; 1945-75; 1978-92	5/29/83	5,350	261
4	13011900	Buffalo Fork above Lava Creek, near Moran	323	1965-present	1966-92	6/09/81	6,540	534
5	13015000	Gros Ventre River at Zenith[1]	683	1917-18; 1987-present	1917; 1988-92	6/07/91	3,400	--[2]

[1]No winter record, data based on available records.
[2]Not calculated because no winter record exists.

[SOURCE: Nolan and Miller, 1995]

Streamflow in the area is both perennial and intermittent. Most streams originate in the mountains and are perennial, although some streams are intermittent along reaches in some years. For example, the Gros Ventre River flowed intermittently for brief periods in 1988 and 1992 (Nolan and Miller, 1995). Streamflow is greatest during May through July in response to melting snow and glacial ice. Streamflow declines in the summer and falls to its lowest level in winter. In late summer through early spring, streamflow is maintained by recharge from the alluvial aquifers hydrologically connected to the streams (Wyoming State Engineer's Office, 1972). Streams in Jackson Hole gain or lose water because they are commonly underlain by moderately to highly permeable aquifers of sand, gravel, and cobbles, and the stream level is continuous with the water table. In general, reaches of streams in Jackson Hole that are topographically high lose water and those that are topographically low gain water (Cox, 1974).

Daily fluctuations in flow are typical during snowmelt periods, with successive daily flows increasing as daylight hours lengthen and temperatures increase. This pattern, if uninterrupted by changing weather conditions, continues until peak flow occurs. Weather conditions can have a significant affect on snowmelt runoff making predictions of peak flows difficult. Streams regulated by dams or irrigation diversions have unnatural-looking hydrographs that have attenuated responses to individual rainfall events or snowmelt runoff (Nolan and Miller, 1995).

The hydrograph of the Snake River above Jackson Lake at Flagg Ranch is an example of a nonregulated perennial stream, and shows responses to snowmelt runoff and rainfall events from April to June, 1992, followed by sustained flow (Figure 3). In contrast, the hydrograph for the Snake River near Moran indicates the flow dampening effect of streamflow regulation at Jackson Lake Dam. The sudden increase in streamflow in May at Moran indicates the release of additional water for irrigation and recreation uses (Nolan and Miller, 1995).

The Gros Ventre River at Zenith (shown in Figure 2) flowed intermittently at various times as observed in Figure 3. Several factors might have combined to cause the Gros Ventre River to flow intermittently in water years 1988 and 1992, including less than normal precipitation, water diversion to supply the southern portion of Jackson Hole, and the losing nature of this stream reach (Nolan and Miller, 1995).

Data are insufficient to determine whether flows were intermittent before 1987 in the Gros Ventre River at Zenith. Except for the current record (1987-present), the only years of record for this gauging station are 1917-18. In 1917-18, streamflow data were collected only during July-September. The minimum observed flow during the 1917-18 period was 121 cfs, which occurred on September 6, 1918 (Nolan and Miller, 1995).

Annual peak discharges for the Snake River near Moran for water years 1904-92 are presented in Figure 4. The discharges were graphed for this period to display the effect of dam regulation on high flow. The data indicate the annual peak discharge generally decreased after 1918.
The apparent reduction in annual peak discharge is consistent with the history of Jackson Lake Dam, a concrete-gravity dam with earth-embankment wings rebuilt in 1917, and again in 1988 (U.S. Army Corps of Engineers, 1989). Releases are generally limited to the 5,000 to 7,000 cfs range during the peak runoff period. During the period of record the Jackson Lake regulation

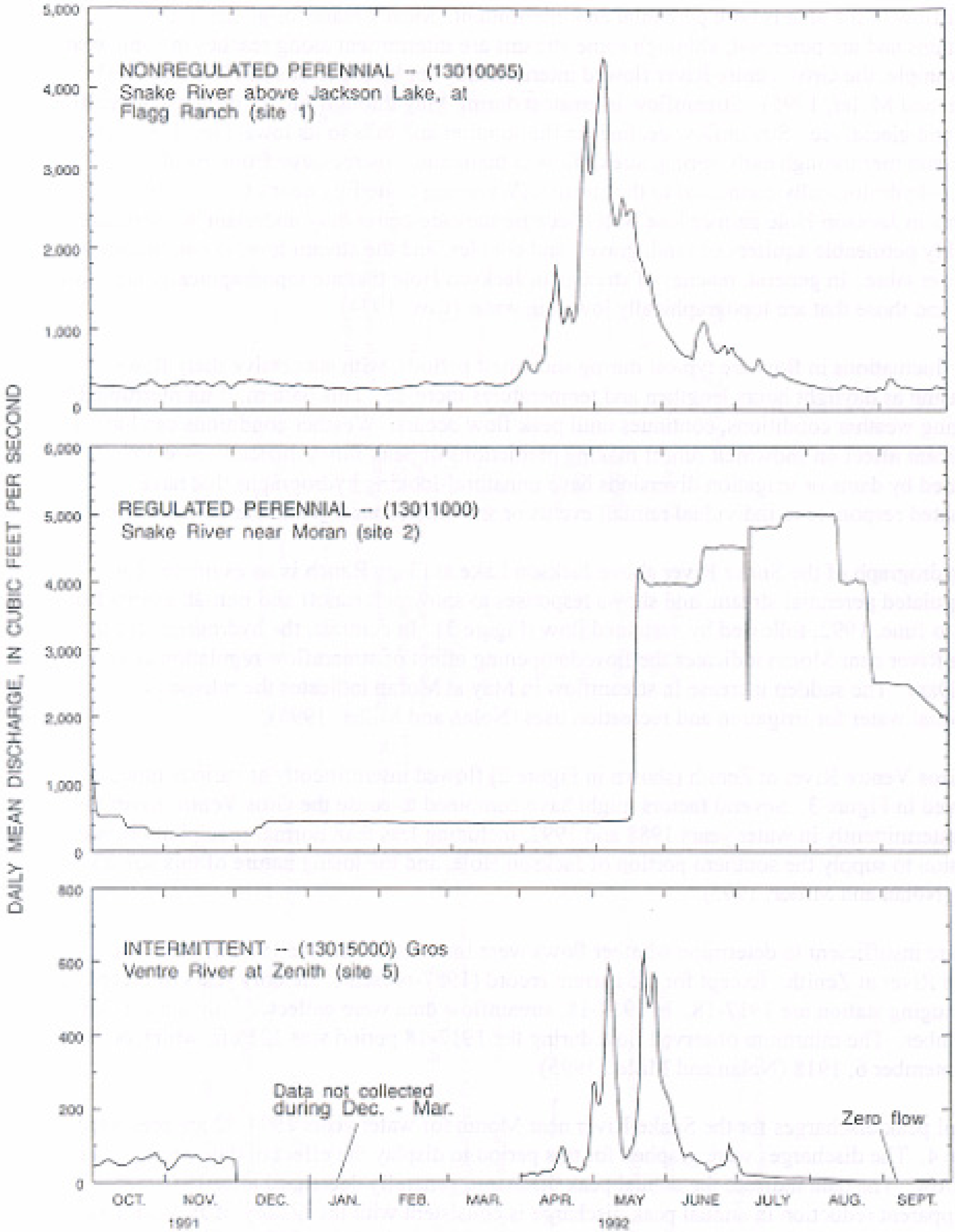


FIGURE 3: Daily mean discharge for selected nonregulated and regulated perennial and intermittent streams in Teton County Wyoming, water year 1992.

[SOURCE: Nolan and Miller, 1995]

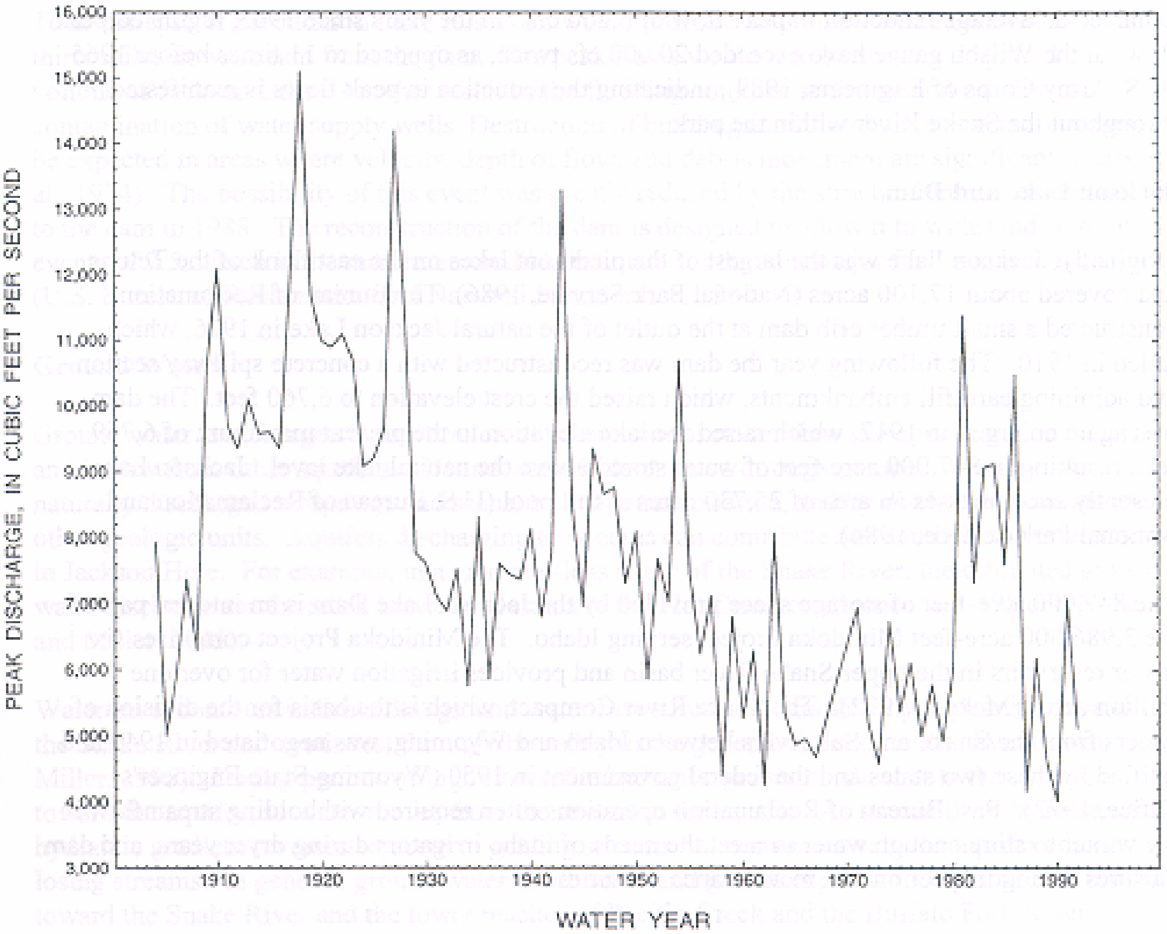


FIGURE 4: Annual peak discharge on the Snake River near Moran, Wyoming water years 1904-92.

[SOURCE: Nolan and Miller, 1995]

achieved an average reduction in peak flow of 6,200 cfs. In the years since 1965, regulated peak flows at the Wilson gauge have exceeded 20,000 cfs twice, as opposed to 11 times before 1965 (U.S. Army Corps of Engineers, 1989), indicating the reduction in peak flows is manifested throughout the Snake River within the park.

Jackson Lake and Dam

Originally, Jackson Lake was the largest of the piedmont lakes on the east flank of the Tetons and covered about 17,100 acres (National Park Service, 1986). The Bureau of Reclamation constructed a small timber crib dam at the outlet of the natural Jackson Lake in 1906, which failed in 1910. The following year the dam was reconstructed with a concrete spillway section and adjoining earthfill embankments, which raised the crest elevation to 6,760 feet. The dam was again enlarged in 1917, which raised the lake elevation to the present maximum of 6,769 feet, resulting in 847,000 acre-feet of water stored above the natural lake level. Jackson Lake presently encompasses an area of 25,730 acres at full pool (U.S. Bureau of Reclamation and National Park Service, 1984).

The 847,000 acre-feet of storage space provided by the Jackson Lake Dam is an integral part of the 3,986,000 acre-feet Minidoka Project serving Idaho. The Minidoka Project comprises six major reservoirs in the upper Snake River basin and provides irrigation water for over one million acres (Mekeel, 1972). The Snake River Compact, which is the basis for the division of waters from the Snake and Salt rivers between Idaho and Wyoming, was negotiated in 1949 and ratified by these two states and the federal government in 1950 (Wyoming State Engineer's Office, 1972). Past Bureau of Reclamation operations often required withholding streamflow in the winter to store enough water to meet the needs of Idaho irrigators during dryer years, and dam closures during inspection and maintenance activities.

Kroger (1967) has documented effects of low flow on the river biota downstream of Jackson Lake. Based partially on Kroger's data, Rollefson and Erickson (1972) estimated annual losses of 31,000 pounds of trout during years when the dam was closed. In addition to physical habitat changes, pH and alkalinity markedly increased in the river following closure of the dam (Houston and Hayden, 1969). Large fish kills have also occurred in the Oxbow Bend area during winters when dam flows have been below 100 cfs. Mortality of beaver in the Snake River has also increased significantly during winters of low flow (Collins, 1977).

The Bureau of Reclamation has jurisdiction over all land below the maximum reservoir elevation and a withdrawn area immediately surrounding the lakeshore to insuring proper operation and protection of the reservoir. This does not preclude NPS development within the operational zone, and all public utilization of the withdrawn area is under the jurisdiction and administration of the NPS (U.S. Bureau of Reclamation and National Park Service, 1984).

Jackson Lake Dam is located on porous volcanic rock and unconsolidated lake bed, glacial, and alluvial sediments (Mills, 1991). BOR studies showed the design and construction methods used to build the dam in the early 1900s, were inadequate for the seismically active area in which it is located and that the dam could fail in the event of a 5.5 (Richter scale) or greater earthquake.

Total collapse of the Jackson Lake Reservoir would produce an outflow exceeding 400,000 cfs thirty miles downstream from the dam. The peak flows would also be sustained by the large volume of Jackson Lake. Another result of the flooding could be sediment and bacteria contamination of water supply wells. Destruction of buildings and flood plain vegetation would be expected in areas where velocity, depth of flow, and debris movement are significant (Glass et al., 1974). The possibility of this event was greatly reduced by the structural improvements made to the dam in 1988. The reconstruction of the dam is designed to allow it to withstand seismic events of 7.5, which is the maximum credible estimate for the four major fault zones in the area (U.S. Bureau of Reclamation and National Park Service, 1984).

Ground Water

Ground water is recharged by infiltration of precipitation, streamflow leakage, irrigation water, and inflow from other aquifers. Ground water is discharged through pumped wells and is naturally discharged by springs and seeps, by evapotranspiration, and by discharge to streams and other geologic units. Aquifers discharging to streams can contribute substantially to surface flow in Jackson Hole. For example, in a gain-and-loss study of the Snake River, the estimated ground water discharge for the reach between Moran and the Flat Creek confluence was 395 cfs (Nolan and Miller, 1995).

Water-level contours indicate that ground water flows from topographically high areas toward the Snake River and southwest through the valley in the general direction of the river (Nolan and Miller, 1995). During periods of high flows, the hydraulic gradient, adjacent to the stream, is toward the aquifer, so water moves from the stream to the aquifer. As stream flow decreases, the hydraulic gradient reverses adjacent to gaining streams but remains toward the aquifer adjacent to losing streams. In general, ground water in alluvium and glacial deposits in Jackson Hole moves toward the Snake River and the lower reaches of Pacific Creek and the Buffalo Fork River, indicating gaining reaches of streams, but moves parallel to or away from several other streams, indicating losing reaches. The largest measured loss from a stream was 11.7 cfs per mile along Cottonwood Creek (Cox, 1974).

Although precipitation is greatest in winter and spring, recharge to aquifers is greatest in late spring and summer when precipitation occurs mostly as rain, snow is melting, and streamflow is highest. Recharge also occurs as water from irrigated lands and leakage from canals and ditches percolates to the water table (Cox, 1974). Most of the streams draining the Gros Ventre and Teton mountains head in carbonate and karstic terrain. Previously conducted dye tracing demonstrated losing streams located on U.S Forest Service lands discharge to springs within Grand Teton National Park (Huntoon and Mills, 1987).

Wells and springs in the vicinity of the park most commonly were completed in or issued from unconsolidated deposits of Quaternary age, and rocks of Tertiary, Mesozoic, and Paleozoic age. The largest discharges measured, reported, or estimated were from Quaternary unconsolidated deposits and totaled 3,000 gallons per minute. Quaternary unconsolidated deposits ranged in thickness from about 380 feet in the northern part of Antelope Flats to about 2,400 feet near the Potholes area in Grand Teton National Park (Nolan and Miller, 1995).

Water Quality

Studies indicate surface and ground waters within the park are of exceptionally high quality, and all surface waters are designated as Class I (the highest of four water quality classifications) by the Wyoming Department of Environmental Quality and meet or exceed those standards. The water quality characteristics of Jackson Lake are typical of snowmelt-fed, high elevation reservoirs and are of relatively high quality all year (Miller and Dustin, 1997). Water temperature, nutrient loading, and turbidity remain low while dissolved oxygen is generally at high levels (U.S. Bureau of Reclamation and National Park Service, 1984). The Snake River, below the dam and for some distance downstream, exhibits the same high quality water observed in Jackson Lake.

A study conducted by Miller and Dustin (1997) was initiated over concern that the quality of the park's lakes may be declining due to increased human usage. A trophic state evaluation, featuring nutrient and chlorophyll-a analyses, was chosen because it is an indicator of a lake's overall water quality. No previous trophic state studies have been performed so trend analysis was not possible.

Seventeen lakes were studied in 1995, and five were resampled in 1996, to provide a baseline against which future changes can be compared. The 1995 study concluded the majority of the lakes were within the oligotrophic to slightly mesotrophic ranges, as would be expected given their pristine natural surroundings and the fact that they are fed mainly from high mountain snowpack runoff. The mesotrophic or unclassified lakes were sampled again in 1996 for further evaluation (Miller and Dustin, 1997).

In Jackson Lake, the waters are primarily oligotrophic, but near developments utilizing sewage lagoons (Colter Bay, east Spalding Bay) the trophic state was found to be slightly mesotrophic. The east Spalding Bay site was determined to be strongly mesotrophic and even in the hyper-eutrophic range (Carlson Scale) at depth, with phosphorus readings of 140 parts per billion (ppb) in June and 250 ppb in July. Chlorophyll-a and transparency also showed departure from the values observed at other sites around the lake. In general, the lake was found to be phosphorus limited except in the case of east Spalding Bay (Miller and Dustin, 1997).

Of the other lakes monitored in the program, only Two Ocean Lake and Swan Lake were determined to be strongly mesotrophic. Additionally, there were 12 species of algae, including the noxious blue-green algae, found in Two Ocean Lake, as compared to only two algal species recovered from east Spalding Bay. The phosphorus source in Two Ocean Lake was not determined; however, it should be noted that six of the eight phosphorus samples collected in the 1996 resampling from Two Ocean Lake were below detection limits (Miller and Dustin, 1997).

During certain portions of the runoff period, tributaries to the Snake River below the dam transport large concentrations of suspended material due to the erosion of unstable streambanks and overland flow during melt (Skinner, 1977; Kiefling, 1978). This sediment constitutes the greatest water quality concern for these streams (U.S. Bureau of Reclamation and National Park Service, 1984). As reported by Clark (1993), the most common nonpoint source problem in the upper Snake River basin is sediment loading caused by irrigated agriculture, rangeland grazing, land development, levee construction, road building for oil and gas development, and off-road vehicle use.

The Snake River upstream from the park, contains fluoride greater than the limit recommended for public supplies but less than the concentration that constitutes grounds for rejection of such a supply (Cox, 1974). Pesticides are used in limited quantities in Teton County in populated areas. Two surface water samples collected downstream from the park in Teton County contained detectable concentrations of malathion, an insecticide commonly used during the summer to control mosquitoes in the Wilson and Jackson areas (Nolan and Miller, 1995).

Mercury samples were collected as part of the U.S. Geological Survey's National Water Quality Assessment Program and mercury was detected in bed sediments at all 14 sites in the upper Snake River basin, including the Flagg Ranch site in Grand Teton National Park at the head of Jackson Lake. The mercury concentration in sediment at Flagg Ranch was measured at 0.05 microgram per gram, which was similar to other reference sites in the basin. The Canadian Ministry of Environment and Energy guideline for mercury in sediment is 0.2 microgram per gram (Maret, 1995b), which agrees with no effect levels documented by several researchers as presented by Irwin (1997). Mercury levels in caddisfly larvae were less than the detection limit of 0.05 microgram per gram (Maret, 1995b). Fish tissue analysis for mercury has been conducted in the upper Gros Ventre River. This sampling was done over ten years ago in association with mining concerns and revealed no abnormal mercury findings. More recent fish tissue analyses have not been conducted in the vicinity of the park (Kiefling, 1998).

McFeters and Stuart (1976) collected water samples from the high alpine zone within the park over four summers. The samples were analyzed for populations of indicator bacteria, fecal coliform, and fecal streptococci. Water that originated in remote areas contained some indicator bacteria, and these populations increased as the water flowed toward the valley. In general, the presence or absence of human visitors did not significantly effect the magnitude of this increase; rather, it was were influenced by the biological community through which the streams flowed. Once in the valley lakes, the indicator organisms dropped to very low levels. The fecal streptococci isolated were identified as the species that occur primarily in the fecal material of native rodent and moose populations. Based mainly on observed human usage patterns, McFeters and Stuart (1976) recommended that sanitary facilities be installed on the upper saddle of Garnet Canyon, and park officials followed this recommendation.

Farag et al. (1997), and Farag and Goldstein (1998) investigated the water quality in Garnet Canyon below the Meadows camp zone. No evidence of fecal coliform, *Giardia*, or *coccidia*, was found, and the general water chemistry differed little from a reference site in Avalanche Canyon. However, human fecal material was observed near Garnet Creek, and it was believed that the lack of rainfall over the period of study may have contributed to the high water quality observed during the study. Fecal coliform was found in Cascade Creek in both 1996 and 1997. The isolated colonies of *E. coli* matched the ribosome patterns of avian, deer, canine, elk, and a human source. Further studies are underway to establish a baseline concerning the human contribution as well as the presence of *E. coli* in other park canyons.

FLUVIAL GEOMORPHOLOGY

The gradient of the Snake and Gros Ventre rivers through the Jackson Hole area is about 19 and 38 feet per mile, respectively. Some reaches of these streams are considered braided, while multiple channel reaches are the most common, and meandering patterns are limited to reaches with lower gradients and sediment inputs. As a result of the gradients, tributaries draining the mountains tend to have high resultant velocities even during low flows. In flood, they transport large bedloads and spread out through an ever increasing secondary network of side channels, eroding the banks, changing courses frequently, and reforming the channel bed during a single flood event (U.S. Army Corps of Engineers, 1989).

The Gros Ventre River is a cobble-bed mountain stream that drains approximately 600 square miles of eastern Jackson Hole and the mountains further east. The river channel is steeply sloped and subject to heavy bedloads originating from rock and cobble deposited by numerous landslides (Love and Reed, 1968). The river is wide and braided in areas where geologic materials are of low erosion resistance, while areas of high resistance result in the river being confined to a single entrenched channel of low sinuosity (Campbell and Lasley, 1990).

Limited geomorphic studies (Skinner, 1977; Marston, 1993; and Mills, 1991) have been conducted in the park on a site/issue specific basis, but a comprehensive analysis of the fluvial geomorphic processes characterizing Grand Teton National Park and surrounding regions has not been conducted. General observations by the author include:

- The streams within Grand Teton National Park drain a recently glaciated and tectonically unstable region. Fluvial geomorphic processes are dominated by mountain building forces and the glacial legacy, resulting in streams that are inherently dynamic because they must continually adjust to changing gradients, sediment supplies, and other factors that control stream “stability”.
- Stream reaches within Jackson Hole, predominantly contain gravel and cobble bedloads, with sand and silt intermixed or deposited in areas of slower velocities.
- As a result of the tectonic lowering of Jackson Hole and the high sediment supply from the surrounding mountains and glacial deposits, streams within Jackson Hole tend to aggrade. The highest rates of aggradation occur near the mountain fronts and several streams flow on alluvial fans where they exit the mountains.
- The Snake River through Jackson Hole is naturally characterized by varying levels of stability, predominantly resulting from proximity to sediment supplies (i.e., very stable from Jackson Lake to Pacific Creek where the lake traps sediment, to unstable below the tributary confluences and terrace cutbanks where sediment is contributed).
- Instability and aggradation are natural phenomenon dominating the region for eons, and the plant and animal life inhabiting the park have evolved to co-exist, and in some cases be dependant upon, this instability.
- The shallow soils typical of the area’s flood plains result in shallow rooted riparian vegetation, which furthers the tendency for high bank erosion and channel dynamics.

The construction of park facilities, such as the headquarters within the Snake River flood plain at Moose, bridges over tributaries, irrigation headgates, streamside campgrounds, and boat accesses, demands a level of stability not naturally present in the region's water courses. Therefore, significant efforts have been made to increase the stability of some stream reaches, requiring large expenditures of capital and manpower and interfering with natural stream and riparian processes. Issues discussed later that effect or arise from fluvial geomorphic processes include road aggregate mining, hydrologic modifications, and flood plain management.

WATER RIGHTS

In 1886, the Wyoming legislature adopted a comprehensive law establishing procedures to be used for the appropriation of water for irrigation. This law replaced the 1875 statute which had maintained the common law principle of riparian rights (Wyoming State Engineer's Office, 1972). According to article 8, section 1 of the Wyoming Constitution, "The water of all natural streams, springs, lakes, or other collections of still water, within the boundaries of the state, are hereby declared to be property of the state." As stated by Stockdale (1995), anyone desiring to use water beneficially in Wyoming must apply for and obtain an approved permit from the State Engineer to appropriate water prior to initiating construction of water-diversion structures, such as dams, headgates, spring boxes, and wells. After the permittee has beneficially used the diverted water for all the permitted uses at all the permitted point(s) or area(s) of use, proof of beneficial use is filed, and the water right is adjudicated (finalized). The adjudication process fixes the location of the water-diversion structure, the use, quantity, and points or areas of use for the water right.

Wyoming water rights are administered using the Doctrine of Prior Appropriation, commonly referred to as the "First in time, first in right" system. Article 8, section 3 of the Wyoming Constitution states, "Priority of appropriation for beneficial use shall give the better right." The priority date for an appropriation is established as the date when the application for permit to appropriate water is received in the State Engineer's Office (Stockdale, 1995).

The State Engineer and the Water Division Superintendents conduct water rights administration. The State Engineer is Wyoming's chief water administration official and has general supervision of all waters of the state. The superintendents, along with their staff of hydrographers and water commissioners, are responsible for the local administration of water rights and the collection of hydrologic data in their respective divisions (Stockdale, 1995).

Deviations from the standard water right administrative system might exist. Such deviations might be caused by conditions in compacts, court decrees, and treaties or through the creation of special water-management districts. Virtually every stream exiting the state is subject to a compact, court decree, or treaty that dictates to some degree how the appropriations on that stream are administered (Stockdale, 1995).

Article III of the Snake River Compact states, "The waters of the Snake River, exclusive of established Wyoming rights (as of 1950) and other uses coming within the provisions of C of this article III, are hereby allocated to each state for storage or direct diversion as follows:

To Idaho...	96 percent
To Wyoming..	4 percent

A Wyoming Instream Flow Law (WS 41-3-1001-1014) passed in 1986 provides a mechanism to convert existing appropriative water rights to instream rights for fisheries protection. Central to the new statute was the recognition of instream flows as a beneficial use of water. The legislation allows for the appropriation of unappropriated water or transferring appropriated water rights for instream flow purposes, which will provide the minimum flow necessary to establish or maintain new or existing fisheries. Instream flows are directly tied to specific stream segments and minimum flow required must be specified. Only the State of Wyoming can own an instream water right (Campbell and Lasley, 1990).

The process of appropriating instream flow requires:

1. The WGFD to perform fishery studies to estimate the minimum flows necessary; identify stream segments and flow rates to be appropriated; and, report their findings to the Wyoming Water Development Commission (WWDC) and the Water Division of the Economic Development and Stabilization Board (EDSB).
2. The EDSB to file applications with the Wyoming State Engineer for appropriation of natural flow in the identified stream segment.
3. The WWDC to analyze whether natural flow is available, whether storage is necessary, or a combination is required.
4. The State Engineer to review the permit application, hold a public meeting, and sign the permit.

As of May 1990, instream flow rights had been applied for on 14 stream segments in Wyoming, three of which were signed (Campbell and Lasley, 1990).

WATER RESOURCE ISSUES

WATER RIGHTS / IRRIGATION

Issues related to water rights and irrigation arise from both local and regional water allocations. Locally, water is withdrawn from the Snake River and its tributaries to provide irrigation needs both internal and external to the park, and commercial and residential withdrawals mainly in the vicinity of the park's southern boundary. Regionally, water stored behind Jackson Lake Dam supports irrigated agricultural requirements mostly in Idaho. This section focuses on local water allocations and irrigation issues; issues arising from regional allocations are discussed in the Hydraulic Modifications section.

Removal of water from park streams changes their base flow characteristic and requires maintenance of diversion structures, altering natural stream dynamics and degrading stream habitat. As inferred from Figure 5, an extensive network of irrigation ditches has been constructed, mainly in the eastern and southern portions of the park. The many irrigation diversions play a major role in determining the amount of water available for habitat in the summer and fall months. In general, the amount of water diverted for irrigation use is more than legally adjudicated (Kiefling, 1978; Albright, 1993; Campbell and Lasley, 1990; Hayden, 1989). Irrigation ditches also change local water table elevations and ground water flow paths, and can create artificial wetlands (Martin, NPS, Water Resources Division, pers. comm., 1997a).

The right to divert water also conveys the right to maintain and repair ditches and diversion structures, even if the diverter is located outside the park and the diversion is within. Structures associated with valid water rights that existed when the park was enlarged in 1950, including ditches and canals and other irrigation structures on federal land, are protected by enabling legislation for the park. Changes in point of diversion or means of conveyance or changes of irrigated lands must be authorized by the state (National Park Service, 1986).

Portions of four natural streams are chronically dewatered under present irrigation practices: Spread Creek, Ditch Creek, Granite Creek, and most significantly, the Gros Ventre River. The diversions provide water for pasture and hay irrigation inside and outside the park, and an amenity to residential and commercial property outside the park (National Park Service, 1986). Generally, the water used in and diverted from the park is not measured, and water flows in many of the diversion ditches most of the year and some of the ditches all year (Cox, 1974).

Most of the diverted water from the Gros Ventre River and Granite Creek flows through canals across the park to private lands under formal grazing commitments, apparently in greater amounts than adjudicated to the permitee. Some ditches carry so much water they continually leak and occasionally wash out. As a result, diverted surface water either seeps into the ground or returns directly to the streams. Some previously agricultural lands adjacent to the park have been developed into residential subdivisions in recent years, but about the same amount of

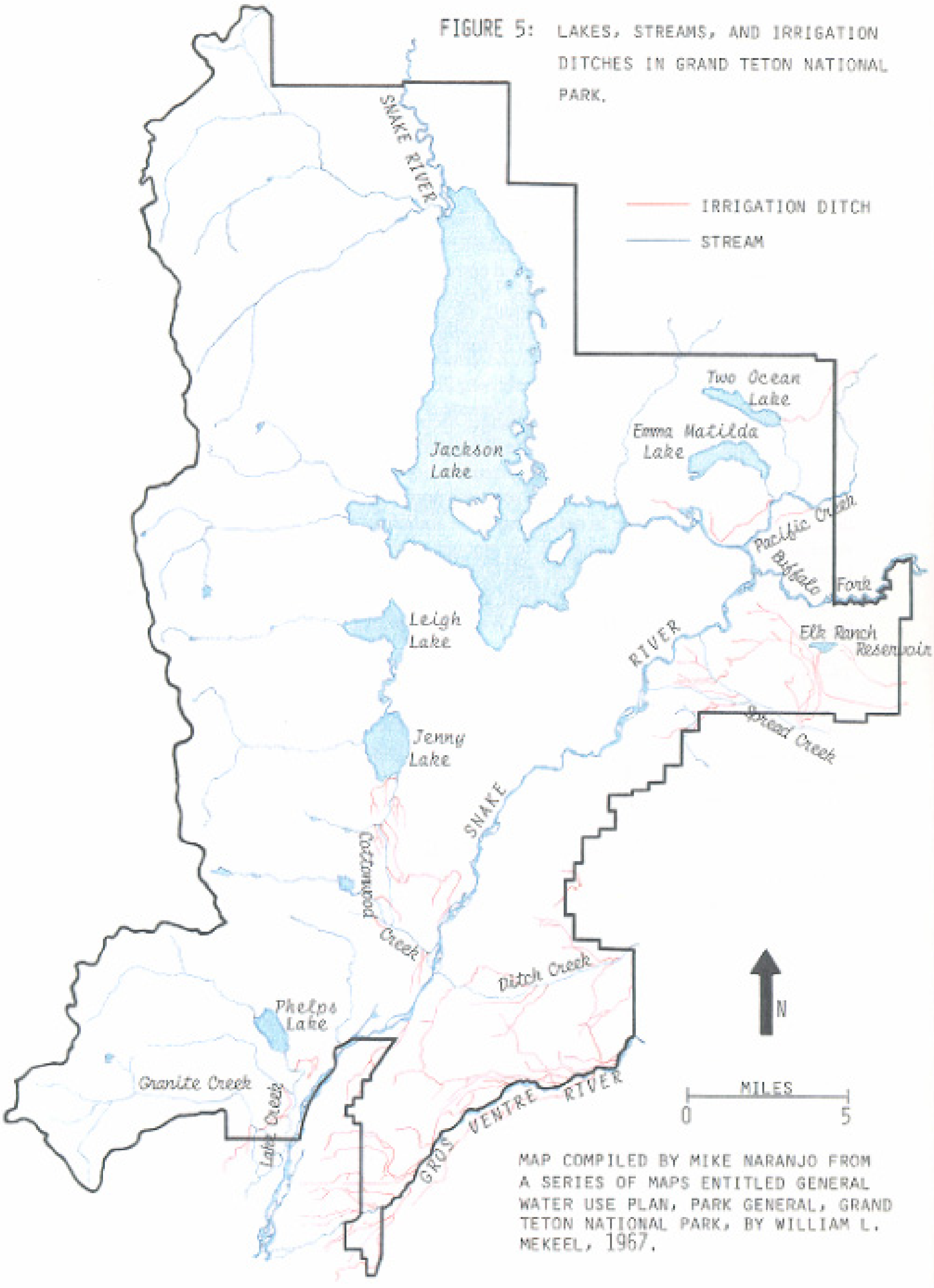


FIGURE 5: LAKES, STREAMS, AND IRRIGATION DITCHES IN GRAND TETON NATIONAL PARK.
IRRIGATION DITCH
STREAM
SNAKE RIVER
Two Ocean Lake
Emma Matilda Lake
Jackson Lake
Pacific Creek
Buffalo Fork
Elk Ranch Reservoir
Leigh Lake
RIVER
Jenny Lake
Spread Creek
SNAKE
Cottonwood Creek
Ditch Creek
N
Phelps Lake
Granite Creek
Lake Creek
MILES
0
5
GROS VENTRE RIVER
MAP COMPILED BY MIKE NARANJO FROM A SERIES OF MAPS ENTITLED GENERAL WATER USE PLAN, PARK GENERAL, GRAND TETON NATIONAL PARK, BY WILLIAM L. MEKEEL, 1967.

water is still diverted to these areas. Apparently, the water is now used to increase the value of residential and commercial properties (National Park Service, 1986).

The Gros Ventre River has been intensively investigated with regard to the effects of irrigation diversions. Annual discharge measurements were taken by the USGS at the Kelly, WY gauging station between 1945 - 1958. This site is located above all but four Gros Ventre River diversions, and mean monthly flows exceeded 200 cfs throughout the summer irrigation months. According to Campbell and Lasley (1990), Hayden (1989), National Park Service (1986), Annear and Bradshaw (1992), and Kiefling (1973), lower portions of the Gros Ventre River have been consistently dewatered on an annual basis for a number of years. This was particularly true during 1988, when the Gros Ventre River's flow reduced to a mere trickle from the Wyoming Highway 26/89/191 (Rockefeller Pkwy in Figure 2) bridge to its confluence with the Snake River (a distance of about three miles), and little water flowed in the six miles upstream from the bridge (Campbell and Lasley, 1990).

The Gros Ventre River fishery is made up primarily of the Snake River cutthroat trout *(Salmo clarki spp.)* and the mountain whitefish *(Prosopium williasoni)*, although the former species is most sought after by area fishermen. Other species found in the lower Gros Ventre River include the rainbow trout (*Oncorhynchus mykiss)*, brook trout (*Salvelinus fontinalis)*, and nine other species (Campbell, and Lasley, 1990). The Wyoming Game and Fish Department has designated the lower Gros Ventre River as a Class 3 fishery (second to last in a four tier classification described as "a fishery frequently of local importance") partly as a function of the low adult trout density, which in turn reflects the poor quality habitat available in this stream reach. Many naturally occurring factors interact to constrain adult trout habitat in the lower Gros Ventre River and were described by Kiefling (1973). These include massive flood effects from the 1927 failure of the Slide Lake Dam, streambank soils lacking fine particulates, weakly rooted riparian vegetation, excessive recruitment of large substrate materials, inadequate recruitment of fine particle sizes, frazil and anchor ice formation, and loss of surface waters to subsurface flows (Annear and Bradshaw, 1992).

Natural limitations to adult trout habitat are magnified by the effects of at least 13 irrigation diversions between Kelly and the mouth of the river. Impacts associated with these diversions typically include stream dewatering, which reduces habitat, and habitat degradation caused by headgate maintenance with heavy equipment. Temporary cobble dams are constructed annually at several diversions to increase flow into the ditches. One reach disturbed by heavy machinery showed a loss of macroinvertebrate populations between 92 - 97 percent (Campbell and Lasley, 1990). The diversion structures can also act as upstream migration barriers to fish (National Park Service, 1986). Since there are progressively more diversions downstream from Kelly, the impacts resulting from dewatering steadily accumulate until fish habitat is virtually eliminated near the Highway 26/89/191 bridge (Annear and Bradshaw, 1992).

Kiefling (1973) established five study segments on the lower Gros Ventre River to determine the loss of aquatic habitat associated with reduced flows and stream alterations. Dewatering at all five sites was extensive and water depths and areas covered by water were inversely related to decreases in flows. An analysis conducted by Annear and Bradshaw (1992) employed a Physical Habitat Simulation Model and Habitat Quality Index to determine if increasing flow in the lower

Gros Ventre River would benefit juvenile and adult cutthroat trout habitat. They concluded trout habitat at the upper site would not substantially benefit from increased flow because the other natural variables, mentioned above, have already defined this stream to be a relatively unproductive Wyoming trout stream. In general, physical habitat at the lower site would benefit from increased flow. The study used average monthly flows in the analysis and looked only at trout habitat, but did recognize that periods of no flow have been documented at the lower site, at which time additional instream flow would be beneficial not only to trout but the entire array of aquatic resources.

The boundary expansion of Grand Teton National Park in 1950 encompassed 14,027 acres of private land. Many of these private lands had allocated water rights associated with their titles. By 1976, the National Park Service had purchased almost 10,000 acres of the private land, and in accordance with Wyoming law the NPS now holds 281 water rights within the park (262 adjudicated, 19 unadjudicated). Most were acquired as appurtenances to lands purchased by or donated to the park. There also remains 72 privately held (alien) water rights for points of diversion and/or means of conveyance or irrigated land within the park. Each 70 acres of land is legally allowed one cfs of diverted water. Original supply refers to the actual appropriation, while supplemental supply involves diverting water from a new direct flow source to lands that already have an original supply appropriation insufficient to provide statutory appropriation. The appropriator is never allowed more than the full amount of the adjudicated water regardless of the source (Campbell and Lasley, 1990).

The State of Wyoming is divided into four Water Divisions administered by the State Engineer and the Water Division Superintendents. Review of Division Four water right records (Campbell and Lasley, 1990) showed a total of 152 adjudicated appropriations of Gros Ventre River water. No evidence of unadjudicated water rights was found. Nine of the appropriations are upstream of the park boundary and total 9.74 cfs of original and supplemental supply for 114.90 acres. A total of 143 appropriations are located within the reach from the park boundary to the confluence with the Snake River. These appropriations total 168.87 cfs of original supply and 75.41 cfs of supplemental supply for 5,278.49 acres. Twenty-two ditches were originally used to convey these diversions, but appropriations using the Buckskin, Hobo, Mesa, and Sabastian ditches have subsequently been transferred to other ditches. Fifty-three percent of the original appropriation of original supply and 22.3 percent of the supplemental supply is owned by the NPS. Private appropriations comprise 44.3 percent of the original supply and 77 percent of the supplemental supply. The National Elk Refuge receives the rest (Campbell and Lasley, 1990).

A number of legal uncertainties are associated with any attempt the National Park Service might initiate to provide some level of instream flow protection to the lower Gros Ventre River. Reviews of water rights dockets by Hayden (1989), Campbell and Lasley (1990), and Albright (1993) revealed National Park Service appropriations formerly used to provide water for irrigation totaling 86.89 cfs are currently idle, along with 3.90 cfs from the U.S. Fish and Wildlife Service. This water is legally adjudicated to the United States, and could greatly improve summer flows in the lower Gros Ventre River, if the water rights could be converted to actual instream flows (Hayden, 1989; Albright, 1993; Campbell and Lasley, 1990).

Tom Campbell, with the Jackson chapter of Trout Unlimited, proposed the National Park Service contribute unused Federal water rights to the Wyoming Game and Fish Department for the purpose of establishing instream flow rights in the lower Gros Ventre River in the late 1980s (Hayden, 1989). Superficially, this appears to be the least contentious way to protect instream flow in the lower Gros Ventre River because the NPS legally acquired these allocations, and simply desires to utilize them for instream flow instead of irrigation.

A review of water rights issues in the lower Gros Ventre River completed by Albright (1993), documented several potential problems with conversion of previously established water rights to instream flow protection under Wyoming water law:

First, park lands in the vicinity of the Gros Ventre River are primarily acquired lands. In many cases, the irrigation ditches associated with these lands have not been used for a substantial period of time. The status of water rights for these parcels is unclear; however, their inclusion in the 1988 "Tabulation of Adjudicated Water Rights of the State of Wyoming—Water Division Number Four, July, 1988", suggests that the state considers them to be current as of that date. If these rights are not converted to other uses, there is the possibility that the State of Wyoming may declare them as abandoned at some time in the future. This would likely precipitate a court action over whether or not the United States abandons property rights in water.

Second, in the case of instream flow protection, Wyoming law requires that instream flow protection allocations be assigned to the state. Advice from the Office of the Solicitor would be required to determine if federal property rights could be assigned to the state in this manner.

Third, even if irrigation allocations are converted to instream flow protection under state law, other provisions of the law may significantly restrict the amount of flow protection that would be achieved for the Gros Ventre River. For example, the state allows only the amount of water that would be consumptively used by the old purpose to be converted to instream flow. Albright (1993) estimated the 86 cfs of NPS irrigation rights may convert to an instream flow protection of only 17 - 26 cfs (assuming 20 - 30 percent as a consumptive use range).

Fourth, the state's instream flow law dictates that conversion to instream flow for the protection of fisheries can not impair or diminish property values of existing water rights along the reach of stream being converted. This would not appear to be a problem in this case because the NPS would convert water rights it already owns and would not be requesting conversion above this amount. However, assuming the Gros Ventre River is not over-allocated, and noting it is still being dewatered, the NPS allocation is probably being used by non-federal water right holders diverting more than their legal allocation. Again, it is unclear whether the state would rule that NPS water rights are abandoned and thus available to others, or if the state would take action against the over-users. The United States will probably need to resolve the status of its own water rights in the Gros Ventre area before the NPS can raise a defensible objection to overdiversion by non-federal water right holders in this same area.

Finally, the Wyoming Game and Fish Department would have to make the determination that the conversion to instream flow would be beneficial to the stream's fisheries, and not just aesthetic or wildlife values which are beyond the limitations of the instream flow law.

Another potential avenue exists for protecting instream flow in the lower Gros Ventre River - establishment of reserved water rights. Application of reserved water rights requires the existence of reserved lands, and the need to establish a minimum streamflow to protect primary reservation purposes. Protection of native fisheries populations is certainly within the scope of primary park purposes. National Park Service lands in the vicinity of the Gros Ventre River include a number of parcels that Bureau of Land Management Master Title Plats depict as reserved lands (i.e., lands that were never patented under private ownership prior to their inclusion in Grand Teton National Park). Seven of these parcels are bounded by the Gros Ventre River and reserved water rights associated with these parcels could be used to protect the fisheries resources in the Gros Ventre River. However, the manner in which the park boundary was established may have effectively removed the Gros Ventre River from NPS jurisdiction because the river channel is included within the National Elk Refuge. This puts the Gros Ventre channel outside the boundaries of the NPS reserved lands. However, the contiguity of the boundary with the river may afford instream flow protection under other legal principles.

If federal reserved water rights do apply, additional study will be needed to quantify the nature and amount of instream flows that can be claimed. Although some of the seven parcels were reserved as part of the Jackson Hole Monument in 1928, it is possible that reserved rights for all seven would carry a priority date of 1950 for national park purposes. A reserved right for instream flow with a 1950 priority date probably would not provide strong protection for fisheries resources since most nonfederal water rights have earlier priority dates. However, this nonfederal right would give the United States a legal standing to protest if over-appropriation by others caused streamflow to drop below the reserved right quantity established for instream flow. Likewise, the adjacent National Elk Refuge, a U.S. Fish and Wildlife administered area established in 1912, probably contains extensive reserved lands and would presumably register a 1912 priority date.

It should also be noted that quantification and assertion of reserved water rights would be protracted and controversial because there is no basin-wide adjudication under way in this area. Also, personal communications in 1997 with Annear, Kiefling, Mullen, Pettee, and Albright indicate the state and other parties would vehemently oppose establishment of reserved rights in the lower Gros Ventre River or elsewhere in the state.

ROAD AGGREGATE MINING

Grand Teton National Park contains many miles of paved and unpaved roads. The congressional authorization that required the Secretary of the Interior to construct a highway to replace H89 (referred to as Rockefeller Parkway on Figure 2) also required that the state be allowed to use material from convenient gravel pits on designated parklands for maintaining the highway. In 1970, the state granted to the United States the right to administer and maintain all roads and highways belonging to the state and county and required the NPS to maintain these roads subject to the availability of funding (National Park Service, 1986).

A report by the Federal Highway Administration (1986) forecast a twenty-year average road surface life within the park and developed the following estimates for the amount of aggregate needed on an annual basis:

units = cubic yards			
Construction	Maintenance	Sanding	Total
1,470,000	1,111,000	33,000	2,614,000

The document also concludes that there is an abundance of road aggregate within the park, but there is a shortage of external commercial sources within feasible hauling distance of the central, eastern and northern park areas.

National Park Service policy requires that new borrow pits not be created in parks or present ones further used unless economic and other concerns make it totally impractical to import materials. There are 38 borrow pits in the park from which at least 100 cubic yards of materials have been excavated. The pits range in size from 0.1 to nearly 40 acres (National Park Service, 1986).

One example of the problems associated with gravel extraction is the Snake River gravel pit, which encompasses approximately 55 - 60 acres of the Snake River flood plain just south of Flagg Ranch. This gravel pit was opened in the 1950's under a U.S. Forest Service permit and was in use until 1992 when the U.S. Army Corps of Engineers ordered a cease of operations due to non-compliance with Section 404 of the Clean Water Act. Enforcement for this case was turned over to the Environmental Protection Agency (EPA). The EPA found 1.07 acres of natural wetlands had been impacted by mining since the site was opened, and that an additional 4.58 acres of regulated pond habitat had been filled. The EPA noted that all the federal agencies (including the NPS) which utilized the pit are obligated to reclaim the site and mitigate the loss of wetlands and other aquatic values (Wagner and Martin, 1996).

In addition to upland sources, nearly every accessible stream has been targeted for gravel mining operations (National Park Service, 1988). In a 1988 Environmental Assessment, the NPS evaluated 15 potential borrow sources and the major issues regarding borrowing activities in the park and surrounding area. The preferred alternative originally called for utilization of commercial gravel supplies south of Jackson. However, the Teton County Commission ultimately supported an alternative proposal to use in-park sites for large jobs and objected to large volumes of gravel being hauled over county roads or through the town of Jackson. The NPS next proposed mining of the Gros Ventre River channel, which met with strong objection from the National Parks and Conservation Association and other environmental groups who felt that out of park sources were preferable in nearly every case.

The Wyoming Game and Fish Department cited no problem with gravel removal operations in the Gros Ventre River in the September to December timeframe; however, they stated such activities during the spring and summer months could inhibit spawning related activities (Kiefling, 1986). Hydrologists (Jackson and Sharrow, 1993) with the Water Resources Division listed a number of limitations and concerns associated with instream gravel mining including:

- There are no generally accepted models of sediment transport and braiding processes in alluvial streams.
- Proposed level of gravel extraction exceeded what consultants mentioned would be feasible.
- The episodic nature of bedload movement in these streams might mean that several years could go by before the mined gravel was replenished and channel restoration would occur.
- The gravel aggrading at bridge crossings is more an indicator of poorly constructed bridges than that the stream is a good place to mine gravel. The mining could ultimately encourage further instability and may lead to more maintenance being required at bridges.

Ultimately, 40,000 cubic yards of material was excavated from the Gros Ventre River channel in 1987, immediately upstream from the Highway 89 bridge on National Elk Refuge lands.

Current proposed construction includes repairing and improving the highway between the Spread Creek bridge and the east entrance sign boundary, and between Moran Junction and the Pacific Creek landing (shown in Figure 2 near the Buffalo entrance station). The environmental assessment for the highway rehabilitation did not consider the possibility of redesigning the highway bridge to allow for more natural migration of Spread Creek over its alluvial fan or changing some of the impacts associated with the road as it passes through the flood plain of the Buffalo Fork River (National Park Service, 1997b). The National Park Service, in cooperation with the Federal Highway Administration and the U.S. Forest Service, also proposes to develop a road material source and staging area at Spread Creek (on U.S. Forest Service lands) to supply aggregate for the highway improvement. The access road, which crosses National Park Service lands, would be reengineered to accommodate large trucks (National Park Service, 1997b).

The Spread Creek drainage area includes about 108 mi^2 and enters the Snake River about 8 miles downstream from Jackson Lake Dam. The upper reaches of Spread Creek cut through slide areas and transport large volumes of alluvial material downstream. Transported material is deposited behind and downstream of a diversion structure located one mile upstream of the park/national forest boundary, adjacent to the proposed mining site (National Park Service, 1997b). Below the diversion, the stream gradient decreases, the water velocity slows, and sediment (sand, gravel, and cobble) deposition increases. As the channel fills with sediment, the banks erode laterally causing the channel to frequently shift, sometimes resulting in major course changes and ultimately forming a wide alluvial fan. Currently, the active channel is 250-300 feet wide, but older abandoned channels are evident over the 0.5 mile-wide fan. The proposed extraction and staging area is out of the base flood plain on an elevated glacial outwash deposit (National Park Service, 1997b).

Wetlands have been identified and mapped along the Spread Creek access road. These wetlands are incidental and artificial, created by seep from an irrigation canal and the damming of water by road fill. There are no wetlands within the Spread Creek staging and borrow area.

HAZARDOUS MATERIALS AND WASTEWATER MANAGEMENT

A list of EPA water supply wells shows 18 wells (as of 1996) in Grand Teton National Park used as public water supply sources. In recognition of the highly permeable alluvial sediments within Jackson Hole and the park's dependence on ground water, a comprehensive Spill Prevention, Control and Countermeasures Plan (SPCC) has been developed (Faler, 1996). The SPCC provides guidelines to prevent and respond to accidental spills of oil, gasoline, diesel, antifreeze, solvents and other hazardous materials, and to mitigate the effects of an occurrence. The plan identified 89 storage tanks within the park, operated by the NPS, concessionaires and others, containing gas, fuel oil, diesel and propane. The document also includes an Interagency Agreement between the U.S. Department of Energy, Idaho Operations Office, and the National Park Service to provide emergency spill response under the terms of the agreement.

Grand Teton National Park has a number of visitor facilities, some of which produce seasonally large volumes of wastewater. None of the park's sewage treatment systems drain into surface waters. Major treatment plants at Colter Bay, Signal Mountain, and Flagg Ranch dispose of effluent through percolation and evaporation. Sewage effluent at Moose and the Gros Ventre River campground is discharged underground. All small systems are of the septic tank-leach field type (National Park Service, 1986). Grand Teton National Park, in cooperation with the U.S. Geological Survey, has collected ground water samples from 13 observation and 10 production wells in or near Grand Teton National Park. Observation wells are located near sewage-disposal ponds at Flagg Ranch, Colter Bay Village, Signal Mountain, and near the sewage drain field at Moose Village. To date, evaluation of the data collected from the monitoring program has not been performed (Young et al., 1991). Ground water samples from the monitoring wells have also been analyzed for hazardous material contamination (Long, 1998).

In 1977, Cox stated that sufficient data have not been collected at developed areas to determine in detail the baseline quality of ground water or the rate, direction, and velocity of movement of percolating effluents. However, theoretical concepts and more recent data suggest effluent percolating near Colter Bay Village is most likely moving southeast and west toward Swan Lake and Colter Bay. Effluent percolating near Moose is most likely moving southeast and south toward the Snake River. Effluents near Flagg Ranch and Huckleberry Lot Springs probably discharge into the Snake River and Polecat Creek, but the amounts are small (Martin, 1997b). In the 1986 Resource Management Plan (National Park Service, 1986), it was stated that insufficient funds are available to continue existing sampling of monitoring wells around sewage treatment lagoons.

Review of the current ground water monitoring program was requested to allow an evaluation of the current program's adequacy, identify necessary modifications to the program (both additions and deletions), and identify probable impacts to natural resources within the park. The review would also ensure that all legally required monitoring is occurring and that park visitors are being provided safe drinking water. The review is described in more detail in the Staffing and Ongoing Programs section, along with efforts to develop a wellhead protection program.

OIL AND GAS DEVELOPMENT

According to Huntoon and Mills (1987), nearly fifty percent of the Targhee and Bridger-Teton National Forest is under lease or has lease applications pending for oil and gas exploration. The Bridger-Teton National Forest Land and Resources Management Plan approved in 1990 identified four management areas available for oil and gas leasing. The four management areas encompass a total of 369,900 acres in the Hoback, Moccasin, Wind River, and the Green River basins. According to the Scoping Statement, " The potential for the occurrence of hydrocarbons is rated as high" (U.S. Forest Service, 1997). The U.S. Forest Service, Bridger –Teton National Forest, is currently developing a site specific leasing analysis tiered to the forest plan, which will include an environmental analysis of identified issues.

The Scoping Statement (U.S. Forest Service, 1997) contains a preliminary list of identified issues, which includes "Effects on water quality and aquatic habitats." According to Anderson (U.S. Forest Service, pers. comm., 1997), only the management area within the Hoback basin drains to the Snake River, but the Hoback and Snake river confluence is several miles downstream from Grand Teton National Park. However, the remaining three management areas lie immediately east of the Snake River drainage, abutting the drainage divide. Given the extensive carbonate strata reported in the mountains forming the divide (Nolan and Miller, 1995; Love and Christiansen, 1985) and the karst hydrology and documented interbasin transfer of ground water (Huntoon and Mills, 1987), there is the possibility that contaminants generated by well drilling and oil and gas production could be carried through the karst ground water network to park tributaries.

HYDROLOGIC MODIFICATIONS

Dams upset streamflow regime by trapping sediment and impeding water flows. Petts (1979) summarized the extensive literature on the geomorphic effects of reservoirs, pointing out that the following adjustments can be expected after reservoir construction: decreases in peak flows, bedload discharge, width, and cross-sectional area; increases or decreases in depth, gradient and sinuosity. Williams and Wolman (1984) found that streambeds degrade below dams for a period of about 20 years following dam closure. Two important considerations specific to the Jackson Lake Dam are: (1) it was constructed at the outflow of a natural lake through which no bedload sediment and negligible suspended sediment were being transported, and (2) peak flows were naturally attenuated to some degree by the storage ability of the 17,100 acre Jackson Lake.

In 1906, the Bureau of Reclamation closed Jackson Lake Dam on the Snake River in what was to become Grand Teton National Park. The operation of Jackson Lake Dam changed Jackson Lake outflow from a run-of-river type natural lake release pattern to a flow-regulated pattern. The release schedule from Jackson Lake Dam has changed over the years as management of the Snake River basin's water for irrigation, and more recently for local recreation and fisheries as well, has evolved.

Four issues are directly tied to the operation of Jackson Lake Dam: lake surface fluctuations, instream flows for protection of fish and wildlife, decrease in the magnitude and frequency of peak flows which maintain fluvial geomorphic processes, and changes in the distribution and character of riparian communities.

Lake Surface Fluctuations

Previous to the construction of Jackson Lake Dam, Jackson Lake's surface elevation was relatively constant and vegetation clung to its shoreline. Currently, summer releases to augment downstream irrigation cause fluctuations of the surface of Jackson Lake, which in turn degrades the aesthetic appeal of the lake shore and makes lake access more difficult. Studies also indicate nearshore macrophyte production can be limited by excessive drawdowns (Brewer, 1988).

Base Flows

Section 9 of PL 87-187 (64 Stat. 849) and a Memorandum of Understanding dated November 29, 1956, between the National Park Service and the Bureau of Reclamation, provide for the operation guidelines of Jackson Lake Reservoir. Congress clearly intended that expansion of the park would not conflict with Bureau of Reclamation operations or the rights of the space holders in the reservoir (National Park Service, 1997a). A former management practice of the Bureau of Reclamation involved closing (or near closing) Jackson Lake Dam during winters of below normal precipitation.

Past low flows reduced species diversity of benthic invertebrates for several miles below Jackson Lake and caused increased alkalinity and conductivity following closure of the dam. Formation of anchor ice in riffles and complete dissection of side channels during winter months resulted in the loss of sufficient numbers of invertebrates as to reduce overall productivity. This in turn was reported to limit fish populations during both winter and summer, since a number of months are required to re-establish benthic fauna. The Wyoming Game and Fish Department estimated that sustained winter flows below 100 cfs resulted in the loss of 31,000 pounds of trout annually (Kerr, 1977). Dewatering also caused a significant component of the Snake River beaver population to move their winter dwelling sites, making them vulnerable to predation and the elements, resulting in increased mortality to both young and adults (Collins, 1977). The section from Buffalo Fork to the Wilson Bridge is the area most critically affected by low flows. Below Wilson, there is enough tributary and ground water input to keep the Snake from being effectively dewatered (Woodin, 1977).

Two recent developments alleviate the concern for maintenance of winter minimum flows in the Snake River. First, the Bureau of Reclamation has recognized the recreational value of fishing and the importance of minimum flows to the productivity of the Snake River cutthroat trout population. Secondly, in October of 1990, a contract was signed between the State of Wyoming and the Bureau of Reclamation to maintain minimum acceptable flow levels of 280 cfs during the winter to protect the trout fishery (National Park Service, 1997a). Additionally, the State of Wyoming has purchased 33,000 acre-feet of water in Jackson Lake to use in augmenting Snake River flows during the second year of a drought. The BOR is also agreeing to routinely maintain 450-500 cfs during the winter (Kiefling, Wyoming Game and Fish Department, pers. comm, 1997). It is anticipated that these measures will alleviate the problem of minimum flow maintenance below Jackson Lake Dam, much to the credit of the Wyoming Game and Fish Department.

Peak Flows

Gauging station data (Marston, 1993) shows the Snake River below Jackson Lake Dam at Moran experienced peak flows greater than 9,712 cfs during 13 years between 1899 and 1945, but only one flow of that magnitude between 1945 and 1955. From 1955 through 1980 no peak flows exceeded this value. In 1981, a flood reaching 11,400 cfs was recorded. Marston concluded the greatest departure from natural stream flows is evidenced as a decrease in the frequency and magnitude of the peak flows, which triggers channel and riparian vegetation dynamics. This change reflects the operation of Jackson Lake Dam as opposed to a shift in climate (Mills, 1991).

Mills (1991) and Marston (1993) assessed horizontal channel stability with field surveys of the Snake River channel morphology and substrate, coupled with interpretation of maps and aerial photographs. Comparisons of Snake River channel maps reveal increased braiding below cutbanks as well as where Pacific Creek, Buffalo Fork, and Spread Creek meet the river's main stem. Due to decreased peak flows, the river has insufficient competence to transport its sediment load in the reaches below major bedload inputs. Therefore, in those channel segments influenced by input of sediment from tributaries and cutbanks, horizontal channel stability decreased. This state is manifested in greater braiding and meandering. Away from sediment sources, the Snake River is characterized by greater horizontal stability because channel avulsions are not as frequent. Outside the zone of sediment influence, braiding and meandering are reduced because fewer avulsions ensue from decreased destructive flushing flows (Mills, 1991).

In summary, the decreased magnitude of peak flows has reduced the Snake River's ability to transport bedloads. Thus, the stream aggrades and avulses in areas of sediment input. Since this sediment is not transported out of these regions in historical volumes, it is not transported to regions without sediment input, and these reaches are thus more stable. Floods, however, have not been eliminated from the channel below the dam. Marston (1993) identified an 11,400 cfs peak flow in 1981, which reversed the processes described above. There is no reason to believe that future floods will not occur, temporarily opening old channels and moving sediment introduced from the tributaries and cutbanks along, if not through, the channel system (Mills, 1991).

Wolman and Miller (1960) determined that large magnitude floods of historic significance are not responsible for the average morphological characteristics observed in river channels. Rather, the bankfull discharge, which has an average recurrence interval of 1.5 years, is the most effective at moving sediment, forming and removing bars, forming or changing bends or meanders, and generally doing work that results in the average morphologic characteristics of channels (Dunne and Leopold, 1978). Although extreme erosion may take place during large floods, it is the modest flows, which often transport the greatest amount of sediment over time, due to the higher frequency of occurrence of such events. Rosgen (1996) has applied the concept of bankfull discharge to address geomorphic instability problems on numerous western streams. A hydrologic analysis, which models stream types (Rosgen, 1996) found in the Snake

River between Jackson Lake Dam and the Gros Ventre River confluence, could determine the bankfull stage and estimate the return interval needed to restore most of the natural geomorphic processes within the river.

Riparian Vegetation

Mills (1991) analyzed vegetation changes within the Snake River flood plain from 1945 to 1989, the earliest and latest years for which aerial photographs were available. The landscape units mapped as riparian were: unvegetated channel deposits, grass covered channel deposits, shrub-swampland of willow-mountain alder, low-density forest of narrowleaf cottonwood, medium density mixed forest of blue-spruce-narrowleaf cottonwood, and high-density forest of blue spruce.

Mills (1991) determined riparian vegetation along the Snake River immediately below Jackson Lake Dam, has responded to changes in the operation of the dam. Flood flows decreased after Palisades Reservoir was completed downstream in 1957. As horizontal channel stability increased, the diversity of the flood plain vegetation increased and forested communities expanded. The trend in landscape diversity over time is toward greater evenness in aerial coverage of climax communities (blue spruce, grass-covered deposits, and bare-ground communities) at the expense of shrub-swampland. The trend was attributed to the decline in destructive flows from Jackson Lake Dam (Marston, 1993).

In contrast, immediately below tributaries and cutbanks, sediment has accumulated at an increased rate, resulting in greater instability in the zone of sediment influence and enlargement of the area of unvegetated channel deposits. Apparent from Mills' (1991) work is that landscape diversity is inversely related to horizontal channel stability. He also notes that diversity of flood plain vegetation communities cannot be completely explained by horizontal channel stability alone, and may relate to grazing and foraging patterns, as discussed later.

Landscape diversity along the Snake River has increased by the expansion of forested vegetation communities, used by raptors, but at the expense of willow-alder shrub swampland, which constitutes prime habitat for moose. The decline in channel avulsions has eliminated numerous side-channels which formerly served as spawning and rearing habitat for the Snake River cutthroat trout. Geomorphic and vegetative adjustments will affect the quality and quantity of critical aquatic fish cover and flood plain wildlife habitat, the river's aesthetic values, flood plain management, and the quality of recreational float trips. Marston (1993) stated that because geomorphic and riparian responses of the river have both positive and negative attributes, the National Park Service will need to decide which factors to stress when suggesting modified release schedules intended to benefit the park's riverine resources.

LIVESTOCK AND UNGULATE GRAZING

Several low order tributaries, generally less than a few miles in length, enter the Snake River from the east and west. Some of these streams are subject to moderate to heavy intensities of wildlife and livestock grazing. Smith et al. (1994) used reference stream reaches with little grazing activity, reaches experiencing only wildlife grazing, and reaches experiencing both cattle and wildlife grazing to correlate grazing intensities with plant community structures. They also measured pool percent, substrate composition, embeddedness, bank stability, canopy, and channel width/depth.

Smith et al. (1994) concluded flood plain and wetland areas show the most impact of grazing and that grazing activities associated not only with livestock, but also with populations of elk, antelope, and bison, are responsible for the foraging noted in riparian areas. They also determined the lowland flood plains characterized by cottonwood communities (preferred forage for domestic and wild animals) are in a successional progression toward domination by Engelmann spruce. Grazing of the deciduous woody species, combined with the previously discussed geomorphic processes, appear to be contributing to this succession. Smith et al. (1993) state, “active intervention in this process through modifying grazing, fluvial processes, and/or fire regimes may provide the only opportunities for long-term preservation of more than remnants of the habitat values currently available in the present deciduous woodland.”

Livestock and ungulate grazing in riparian areas can also be detrimental to streambank stability through trampling of banks and streamside vegetation. As stated by Rosgen (1996), “Improper grazing can change the composition of riparian vegetation communities, and in so doing…cause adverse stream channel adjustments…include[ing]: accelerated bank erosion, increased width/depth ratios, altered channel patterns, induced channel instability, increased sediment supply, decreased sediment transport capacity, and damaged fisheries habitat.” Direct access to streams can degrade water quality not only through the input of sediments, but also by increased contributions of bacteria and nutrients. The alterations to physical habitat and water quality have been linked to changes in macroinvertebrate community structure within park streams (Meier and Travers, 1996).

FISH STOCKING

Maret (1995a) stated, “The biological consequences of introduced fish populations (in the Snake River basin) are not known; however, interspecific competition with native species and introduction of harmful diseases or pathogens to the aquatic environment are possible.” As early as 1890, the U. S. Fish Commission had introduced both brown trout (*Salmo trutta*) and lake trout (*Salvelinus namaycush*) into two lakes in the drainage. Within a short period of time, both species drifted into Jackson Lake and other waters within the drainage. Currently, lake trout inhabit many surrounding lakes, whereas brown trout are mostly confined to the Snake River and Jackson Lake (National Park Service, 1997a). Since 1929, the Wyoming Game and Fish Department has stocked hatchery fish every year except 1938 in one or more waters now within the park. Presently, four nonnative salmonids inhabit the upper Snake River drainage.

In 1986, the National Park Service reported the WGFD prohibited stocking of rainbow trout in the upper Snake River basin because of possible hybridization with native cutthroat trout. The NPS (1997a) stated that in 1993, WGFD introduced both the brook trout (*Salvelinus fontinalis*) and the rainbow trout (*Oncorhynchus mykis*) into the drainage. Brook trout are currently found throughout the drainage, though they prefer smaller streams and beaver ponds. The few remaining wild populations of rainbow trout are infrequently found in Jenny Lake and sections of the Gros Ventre River. Other than in Jackson Lake where lake trout are stocked, only hatchery reared cutthroat trout or their eggs have been stocked within the park since 1966 (National Park Service, 1986).

Jackson Lake is the only area (special use zone) in which stocking of fish is acceptable under present NPS guidelines. Most other waters in the park are in defined natural zones, and stocking in these areas violates NPS fisheries policy. The WGFD claims sole jurisdiction over all fishery management and has resisted attempts by the NPS to share in or influence these programs. This has resulted in disputes over the years involving fishing regulations, fish stocking, removal of beaver dams to enhance cutthroat trout spawning, use of bait fish, vehicular access, use of motorboats and snowmobiles, habitat improvement, manipulation of native non-game fish populations to improve trout fishing, law enforcement, and aquatic research. In most cases, disputes have been resolved in favor of the WGFD (National Park Service, 1986).

FISHERIES RESTORATION / ENHANCEMENT

Of special concern within the park's ecosystem is the Snake River cutthroat trout, representing one of two large natural river populations left in the world (the other being the Yellowstone cutthroat trout). Virtual stoppage of discharge from the Jackson Lake Dam during annual inspection periods, coupled with heavy fishing pressure, disrupted the cutthroat population in the past (National Park Service, 1976). Tributary streams provide spawning and nursery habitat and are essential to the maintenance of the Snake River cutthroat trout. Wyoming Game and Fish Department personnel suggest that the ultimate key to the maintenance of the Snake River Cutthroat Trout fishery is availability of spawning gravel. Areal extent and quality of spawning gravel in tributaries has been reduced through dewatering, siltation, lack of adequate flushing, sedimentation of gravel from return irrigation flows, and blockage of certain streams with headgates and culverts (Kiefling, 1978).

The WGFD (National Park Service, 1997a) has determined that loss of spawning gravels could be offset to some degree if spring-fed creeks, such as upper Bar BC, were developed to their maximum spawning capacity. Prior to the establishment of Grand Teton National Park, the U.S. Bureau of Fisheries constructed a fish hatchery on East Fork of upper Bar BC. Small dams were constructed on the East Fork, near the hatchery site, to provide rearing ponds. There was also evidence the channel above and below the rearing ponds was widened for some purpose. After the hatchery was abandoned, dams were left intact and sediment accumulated in the ponds. In 1984, in cooperation with the National Park Service, WGFD used a backhoe to remove three of the dam structures, and excavate and expose gravel to a limited extent. The work was accomplished on the section of creek adjacent to and below the hatchery site. Personal communication with Kiefling (1997) indicates that spawning pairs have returned to this section of the upper Bar BC Spring Creek and have utilized the restored spawning beds.

The Wyoming Game and Fish Department (1997) is currently recommending the project be continued on the East and Main Forks of the upper Bar BC in an attempt to establish a spawning run similar to that in the lower reach of the West Fork. This will involve removal of the remaining dam structure, which was left intact (due to the last landowner's request), removal of sediments, narrowing the channel to a natural width, excavation of natural gravels or placement of commercial washed gravels where natural gravels cannot be reclaimed, placement of overhead cover (trees) for protection of spawning fish, and escape cover for fry. The estimated cost of the project is $10,000, and WGFD note the benefit to the Snake River fishery would be long-term because Bar BC Spring Creek is located on a bench above the active flood plain.

Park staff is uncertain where the WGFD plans for upper Bar BC Spring Creek cease to be a restoration program and become enhancement. While restoration, such as dam removal and reclamation of fluvial geomorphic parameters is to be encouraged, enhancement runs contrary to NPS policy.

FLOOD PLAIN MANAGEMENT

As a result of low bank strength, high gradients, aggradation, seasonally high flows, and other factors, streams flowing across the surface of Jackson Hole sporadically rework the alluvial sediments they transect. This can be directly observed in the braided pattern manifested by many of these streams. Chronically unstable reaches occur where tributaries to the Snake River cross alluvial fans. These channels can shift hundreds of feet in a single high flow event. The construction of infrastructure in the vicinity of these streams will, sooner or later, become an issue. Currently, levees, bridge crossings, river access points, irrigation diversions and ditches, and developed areas are confronting the park's dynamic stream channels. Only careful and detailed fluvial geomorphic characterizations of these streams will reveal the best ways to preserve their natural functions in light of existing infrastructure.

Levees

According to analyses conducted by the U.S. Army Corps of Engineers (1992), the Snake River has cut an incised channel or meander belt below Jackson Lake Dam which becomes progressively shallower in the downstream direction. Below Moose, the channel widens and becomes progressively more braided and unstable. Multiple main channels and numerous secondary branches spread out over a flood plain up to 8,000 feet wide. During flood periods, the secondary channels become active, spreading flow over a wide area. Prior to 1955, levee and bank protection works consisted mostly of small, discontinuous projects designed to provide local protection. These projects included a wide variety of rock and timber crib dikes, fences, and channel plugs.

Congress, in the Flood Control Act of 1950, authorized a flood control project along the Snake River. Following this authorization, the Corps of Engineers designed the main system of levees on the lower reaches of the Snake River within Jackson Hole. The levees were constructed during the period 1957 to 1964 at a cost of $2,180,000. This system consists of twenty-three miles of revetted levees and about seven miles of "temporary levees" (U.S. Department of

Agriculture, 1982). The 11,600 feet of levees within the park do not directly protect developments, but are upstream extensions designed to tie into high ground.

The levee structures block the lateral spread of the Snake River, reducing the flood plain width and channel braiding. Channel migration and avulsion activity is concentrated between the levees and increases the frequency of attack on vegetated areas. Channel bed material is reworked more frequently and fine material was more likely to be carried through the system rather than being deposited in slower secondary channels. All but one leveed reach has experienced a lowering of thalweg (the line connecting the lowest points along a stream bed) elevation by as much as seven feet (Figure 6). The U.S. Army Corps of Engineers (1992) estimated 3.1 million cubic yards of material was lost from the leveed reach over a 34-year period.

Before the existing levee system, fish habitat was primarily found in numerous small side channels with abundant cover from islands, banks, and vegetation. The levees have cut off many of the smaller side channels previously used by fish. High flows constrained by the levees have eroded many of the islands and vegetation away, and today fish habitat is found mostly in two main channels just inside each levee. Cover is now predominantly found along the levees associated with rock riprap (U.S. Department of Agriculture, 1982). Levee maintenance necessitates almost annual channelization, which is especially destructive and eliminates nearly every element of trout habitat (Kiefling, 1978).

Another levee system is located along Pilgrim Creek, just east of Jackson Lake Dam. The left abutment of Jackson Lake Dam is located on the alluvial fan deposited by Pilgrim Creek. Following construction of the dam, Pilgrim Creek changed course and flowed below the dam to confluence with the Snake River. This realignment brought Pilgrim Creek close to the former location of the town of Moran, which resulted in the town site being occasionally flooded. The Bureau of Reclamation subsequently built a series of levees to push Pacific Creek north into Jackson Lake and alleviate the local flooding problem while providing additional flood control in the Snake River (Smillie, NPS, Water Resources Division, pers. comm., 1997).

The U. S. Army Corps of Engineers, after reviewing a BOR application for levee maintenance under Section 404 guidelines, determined the levee system was not well justified because the town of Moran no longer exists in its former location, and flood control on the Snake River can be accommodated through modified dam releases. The BOR justified the levee maintenance through dam safety concerns, but recognized the left dam abutment could be armored.

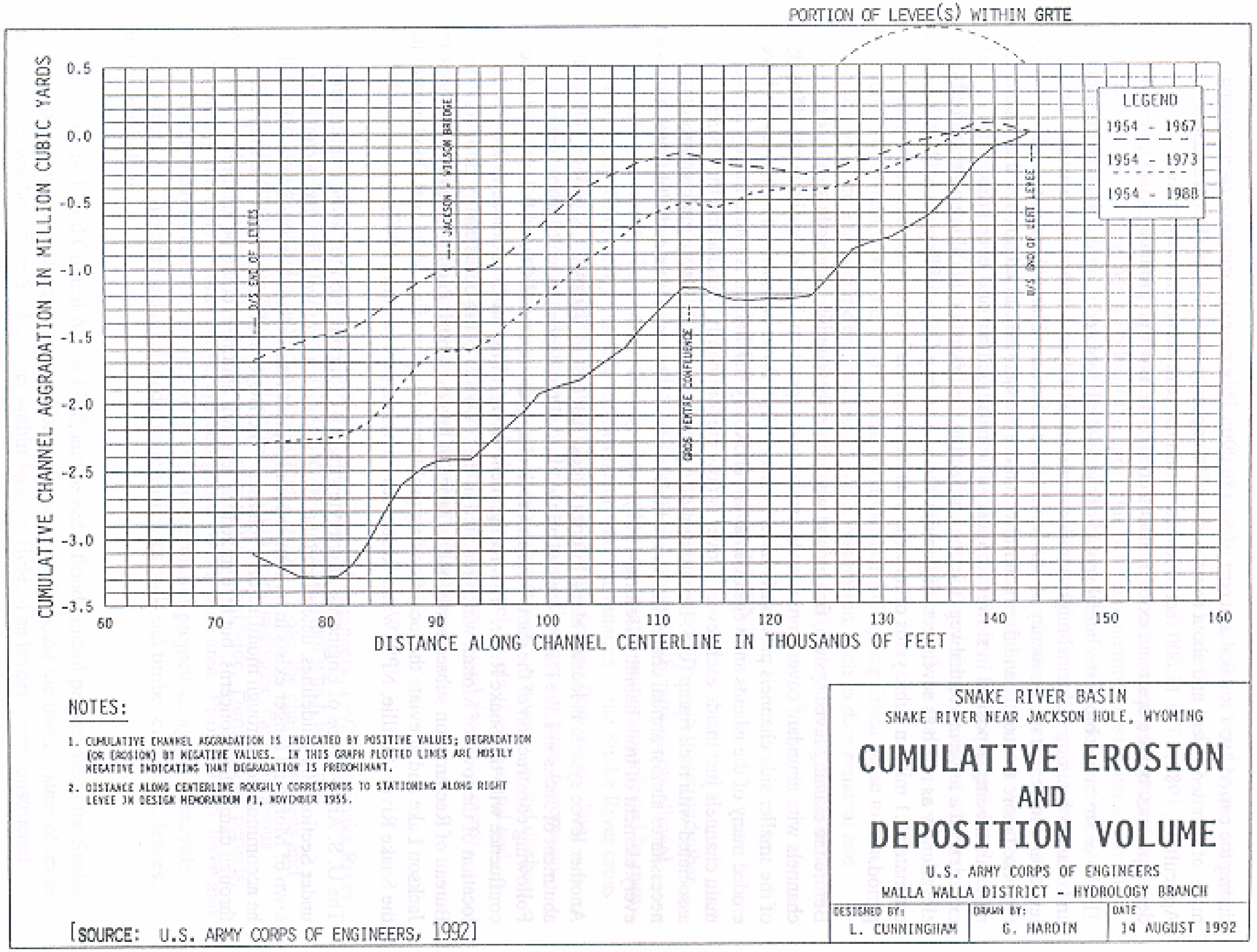


FIGURE 6: RELATIVE LOSS OF SNAKE RIVER CHANNEL ELEVATION WITHIN THE FEDERAL LEVEE PROJECT.

The U.S. Army Corps of Engineers determined that a thorough assessment of alternatives must be conducted before a new 404 permit is granted. If the analysis concludes that further channelization and levee construction is unnecessary, it may restore the natural migration dynamics associated with Pilgrim Creek. The restoration of natural processes should be encouraged because this would be more in keeping with park purposes; however, restoration could eventually have implications for park infrastructure and existing resource conditions such as:

- Migration of Pilgrim Creek could eventually put the stream in the vicinity of the Teton Park Road.
- The Willow Flats area, which provides important moose habitat, could be dissected by an active stream channel.
- Sediments brought in below the dam by Pilgrim Creek could partially fill-in or destabilize the Oxbow Bend area.
- Spring Creek, which presently arises from the alluvial fan could capture Pilgrim Creek, causing Spring Creek to lose all value as a spawning area for cutthroat trout.

The above implications are all natural functions, which could be accommodated or naturally offset. For example, the Teton Park Road could be modified to accompany passage of Pilgrim Creek; moose habitat would develop in other areas; sediment contributions to Oxbow Bend have occurred during previous Pilgrim Creek migrations; and, another spring creek might develop elsewhere on the alluvial fan. The National Park Service is currently working with the Bureau of Reclamation in the development of an alternative analysis for the Pilgrim Creek levee.

Bridges

Skinner (1977) investigated river instability patterns and cobble bed deposition along several streams in Jackson Hole within the park. Skinner utilized photo interpretations of channel migration over a ten year period; conducted on-site visits to characterize sediment size distribution, streambank stability, bridge alignment, and other aspects; used topographic data to produce stream profiles; and, characterized channel sinuosity and valley gradients. He ultimately provided engineering recommendations for improving river pattern stability, reducing cobble bed material transport, and reducing aggradation of bed material in the vicinity of bridge openings.

Skinner noted poor bridge alignment and design, which tends to produce backwater effects and enhance deposition of sediment upstream from the bridge over the Buffalo Fork River. He also noted that bulldozer work, used to flatten and widen the channel upstream from the bridges, encourages deposition of material. The author makes several recommendations, mostly engineering in nature, such as rip-rap, cross-channel cribs, spur dikes, drop channel chutes, selective material removal, and cross-section cleaning and shaping, some of which would cover extensive lengths of some streams.

River Access Maintenance

At some access points (Deadmans Bar for example), gravel builds up and impedes launch use. At other locations (Schwabacher), streambank erosion has mandated repair and relocation of park facilities. While at other locations (Pacific Creek and Moose), both processes appear to be occurring. As stated in the Snake River Management Plan (National Park Service, 1997a), the number and location of launch sites needs to be reviewed and alterations to the landings evaluated including: slip clearance or dredging, alternate locations as the river character changes, or permanent versus temporary landings designated.

The preferred alternative, identified in the Snake River Management Plan, will allow continued minor dredging at launch sites. Gravel removal will be conducted to provide reasonable access to the visitor when necessary. Dredging will be conducted in the immediate vicinity of launch areas, but only when deemed necessary by park managers. The plan also calls for a research and monitoring program to be developed to fully evaluate long-term effects of dredging at the launch areas (National Park Service, 1997a).

Smillie and Keough (1997) conducted field investigations of river access points and provided site-specific observations and recommendations for each. They noted that stream channel manipulation often results in unexpected consequences, and a better understanding of fluvial hydraulics needs to be developed, especially in the Moose and Pacific Creek areas, before effective, long-term management actions can be developed. The first study recommended by Smillie and Keough, would involve monitoring and quantifying bank erosion and could be accomplished by park staff. The second recommended study would include a hydraulic analysis that incorporates the operation of Jackson Lake Dam, the presence/absence of gravel bars, the possible backwater effect from the downstream bridge at Moose, and the potential responses to various stabilization techniques. They conclude that "no serious consideration for bank stabilization should occur until the need is clearly demonstrated by quantitative monitoring and hydraulic modeling."

Flood Plain Developments

Executive Order 11988 (42 FR 26951; May 24 1977) requires that all federal agencies avoid, to the extent possible, the adverse impacts associated with the occupancy and modification of flood plains and avoid direct or indirect support of flood plain development if there is a practicable alternative. The preferred method for satisfying this requirement is to avoid actions on the base (100-year) flood plain. The NPS published revised Floodplain Management Guidelines in 1993 (National Park Service, 1993). The guidelines require delineation of flood plains and flood hazards, determination of the impacts of proposed actions on flood plains through National Environmental Policy Act (NEPA) compliance, and, in areas previously harmed by human activity, requires the development of management plans to evaluate reestablishment of an environment in which the natural ecological systems of the flood plain can function.

Bill Jackson and Gary Smillie (Smillie, 1991) reviewed the Floodplain Statement of Findings for the Teton Corridor Development Concept Plan. The preferred alternative would remove all structures from the 100-year flood plain, relocate irreplaceable articles outside the probable maximum flood plain, and provide for flood-proofing critical items (such as fuel tanks) that would remain in the 500-year flood plain. The visitor center (at Moose) would be relocated to another site presumably outside of all flood plains. At the time of this writing, the NPS was enlarging the maintenance facilities at Moose, and it would appear the recommendation to move the Moose compound out of the Snake River flood plain has been abandoned.

Smillie and Keough (1997) report that the Moose complex is within the natural flood plain of the Snake River and has not experienced flooding in recent years only because of the flow regulation afforded by Jackson Dam upstream. They point out that under certain conditions, flood waters could enter the Moose developed area either by high flow in the river adjacent to the area or by flow breaking out from some point above and flowing in the flood plain down to the developed area. Should breakout occur, damage to many facilities could result, in particular the sewage treatment plant and bridge. They recommend an accurate flood hazard analysis be performed which delineates the areas most susceptible to overbank and breakout flows, and identifies the frequency of such out-of-bank flow. The characteristics of the flows should also be identified, such as the depth and velocity predicted for various design floods.

Other developments exist within Jackson Hole flood plains such as the Gros Ventre River campground and Cottonwood Creek housing area. Some of these developments are not only potentially threatened by flooding, but also by stream channel migrations.

RECREATION

Recreational activities, such as camping, hiking, floating, snowmobiling and horseback riding, can result in detectable water quality degradation in heavily used areas. Examples include pathogens associated with human waste, nutrients and turbidity from cleaning and bathing, leaking hydrocarbons, and erosion of trails and streambanks. Recent *E. coli* studies (Farag and Goldstein, 1998) have documented human waste influencing backcountry water quality. Continually expanding visitation and shifting recreational patterns, such as increased horse use, have the potential to further elevate *E. coli* counts. Because backcountry users often utilize raw water for drinking purposes, and to protect the pristine nature of park waters, water quality monitoring is being conducted, and mitigation measures implemented, as appropriate, in heavily used areas.

STAFFING AND ONGOING PROGRAMS

Dr. Robert Schiller heads the Grand Teton National Park’s Division of Science and Resource Management and reports directly to the superintendent. The division consists of one permanent and a term Wildlife Biologist, a Vegetation Management Specialist, a Cultural Resource Specialist, a Geographic Information System Specialist, and a Park Planner. Kit Mullen, Management Assistant, has primary responsibility over water rights issues. Seasonal positions are added during summer periods.

Ongoing programs include:

National Water Quality Assessment Program – In 1986, the National Park Service contracted with the U.S. Geological Survey to monitor water quality on the Snake River at Flagg Ranch in an effort to determine background water quality conditions entering the park. In 1992, the Flagg Ranch site became a National Water Quality Assessment (NAWQA) program fixed-station reference site (Long et al, 1997). In 1996, the NPS provided funding and cooperated with the NAWQA program to install a new streamflow gauge and collect water quality and ecological data from the Snake River at Moose. The addition of the downstream site was important to assess potential impacts from recreation, wastewater treatment, aggregate extraction, irrigation, and stream channel manipulation. Continued NPS Water Resources Division funding of either NAWQA site is unlikely after 1998 (Martin, 1997b).

Ground Water Monitoring – The U. S. Geological Survey has been conducting ground water quality monitoring in the vicinity of sewage disposal lagoons and leach fields for about 25 years. The monitoring currently exceeds the requirements of the Wyoming Department of Environmental Quality (Martin, 1997b). To date, no scientific interpretation of these data has been conducted which could be used to assess the adequacy of the current wastewater treatment systems or the monitoring program. The U.S. Geological Survey is currently under contract to conduct these interpretations and provide recommendations. This analysis will take into account the adequacy of: treatment prior to allowing the treated wastewater to infiltrate to the ground water system, water quality of the treated effluent, local hydrogeologic conditions, distance to ground water discharge areas, and potential for dilution of effluent along ground water flow paths. Sensitive natural areas down gradient from wastewater disposal ponds will be identified, and if necessary, recommendations for monitoring in those areas will be provided.

Since the U.S. Geological Survey could not contribute matching money, they are anticipating a $10,000 shortfall in this project. Additionally, the NPS needs to work with the U.S. Geological Survey to renew the interagency agreement governing the ground water quality monitoring at sewage disposal sites.

Baseline Water Quality Inventory and Analysis – The NPS Water Resources Division and the Servicewide Inventory and Monitoring Program are coordinating an effort to characterize baseline water quality using existing data relative to Grand Teton National Park. The inventory and analysis includes: (1) determining the water quality retrieval area, (2) downloading and assessing the quality of the data from STORET and other sources, (3) generating basic water quality summary statistics and graphic plots, and (4) reformatting water quality data for compatibility with the park-based Water Quality Data Management System presently under development.

The goal of the inventory and analysis report is to provide descriptive water quality information in a format usable for park planning purposes (such as Water Resources Management Plans, Resource Management Plans, and General Management Plans). The report is designed to address baseline water quality, identify potential water quality problems, and establish a water quality database. This document will also enable park managers to compare and contrast results with historical water quality trends and foster better designed water quality inventory and monitoring programs in the future. Service-wide, the water quality databases can be used by Regions and Washington offices to generate regional and national assessments of park water quality.

Developing Total Maximum Daily Loads (TMDLs) – Clean Water Act Section 303(d) requires states to list and prioritize waters that do not meet water quality standards following the application of technology based controls for municipal and industrial sources of pollution. For each waterbody or segment identified on a 303(d) list, the state or EPA must develop TMDLs that establish allowable loading or other quantifiable parameters for the waterbody. The Wyoming Department of Environmental Quality and the U.S. Environmental Protection Agency are cooperating to develop a plan to implement Total Maximum Daily Loads (TMDLs) for approximately 300 waterbodies identified on Wyoming's "303(d)" list (Rosenlieb, 1997a). According to the Wyoming Department of Environmental Quality (1996), fourteen miles of the Gros Ventre River, thirteen miles of Pacific Creek, and twenty-two miles of the Snake River are 303(d) listed.

Rosenlieb (1997b) states that the development of TMDLs may affect the park in two ways: (1) The implementation can improve water quality of streams tributary to park waters, and (2) Grand Teton National Park may be required to prepare TMDL action plans if impaired stream segment(s) are found inside park boundaries. Rosenlieb also notes that after revision of the 303(d) list in 1997, only segments of Pacific Creek inside and outside the park boundary remained listed, but no reason was given for the listing. Rosenlieb will continue representing the National Park Service regarding development of the 1998 303(d) list and other aspects of the TMDL implementation.

Wellhead Protection Program – Several potential sources of ground water contamination are present within the park. These include: wastewater treatment lagoons, abandoned wells at old ranches, underground storage tanks, and park maintenance facilities. At least eighteen public drinking water supply wells are located within the park. To more effectively safeguard ground water resources, a wellhead protection plan is being developed in cooperation with Brigham Young University and the U.S. Geological Survey. The planning will include: identification of all public water supply wells, delineating the zone of contribution for each well, identifying potential sources of contamination within the contributing area of each well, development of a management plan to minimize the potential for accidental spills or contamination, and development of a contingency plan for alternate water supplies if contamination should occur. The majority of the field work has been completed and a report is expected in late spring, 1998 (Martin , 1997b). Since the U.S. Geological Survey could not contribute matching money, a $10,000 shortfall is anticipated for this project.

Evaluate Trophic Status of Selected Lakes – Trophic state evaluations reported by Miller and Dustin (1997) of selected mountain, moraine and valley lakes indicate some strongly mesotrophic to eutrophic conditions. Additional sampling and evaluation is being conducted in the valley lakes that have demonstrated higher than normal levels of nitrogen and phosphorus. Preliminary data (Miller and Bellini, 1996) indicate that several lakes may be impacted by contaminated ground water flowing from wastewater treatment ponds. The additional sampling is designed to better define probable sources and the severity of impact.

Snake River Pit Monitoring – The U.S. Geological Survey is currently collecting hydrologic data from 15 ground water piezometers and 7 stream stage gauges. These data, which indicate recharge of the area during the winter and spring, and drawdown in summer, will be used to aid the development of restoration and reclamation plans for this site (Martin, 1997b). Since no abrupt or erratic water level fluctuations were observed, the monitoring schedule will be changed from weekly to twice per month. Martin also recommended an interagency agreement be developed to define the monitoring to be conducted at the Snake River gravel pit.

Spread Creek Site Monitoring – Water table monitoring is also being conducted at the proposed Spread Creek gravel pit. Five of the six wells completed at this site were dry most or all of the year, providing little information regarding depth to water and seasonal fluctuations in the water table. Martin (1997b) concluded the water table at the Spread Creek site is generally more than 20 feet below ground surface. He recommended that monitoring of these wells be discontinued and that new, deeper wells will need to be constructed if there is a reason to know the actual depth to water and seasonal fluctuations in the water table.

Open Space Study – Currently being discussed in Congress is the concept of an open space study to determine the possible impacts of large tracts of private lands, currently used for cattle grazing and related activities, adjacent to the park's southern boundary being subdivided and developed. These lands are located along major migration corridors and within scenic viewsheds. The study, which is not funded in any manner, may ultimately influence land management adjacent to the park, as well as grazing and irrigation within the park and access of livestock to park streams.

Water Planning Process - A developing state program which could influence water resource management at Grand Teton National Park is the updating of Wyoming's water planning process to "help ensure that all of Wyoming's citizens benefit from the efficient management and conservation of the state's most valuable resource" (Besson and Fassett, 1997). The first step in the process is to identify individuals with knowledge, interest, and experience in Wyoming's water and related natural resources, and to survey these individuals to develop priorities and issues to be addressed in the planning process. According to Schiller (1997, NPS, Grand Teton National Park, pers. comm.), the park's present staffing limitations do not allow the park to participate in the planning process. This planning process might represent a legitimate avenue for the NPS to interject their concerns regarding stream dewatering, conversion of water rights to instream flow protection, and related matters.

RECOMMENDATIONS

Issue specific recommendations are withheld due to the complex nature of the park's physical, biological, and political environments, and the relatively short time allotted to the scoping effort. Only very thorough, site-specific knowledge of the region's complex hydrologic and biologic processes, applicable laws, National Park Service mandates, park management concerns and constraints, local, state, and federal agency relationships, legislative history, and a myriad of other factors, will allow specific recommendations to be legitimately put forth. It is therefore recommended that a more detailed Water Resource Management Plan be developed which identifies water resource issues, needs, and priorities in much greater detail. Issue specific recommendations would then be developed in coordination with other agencies and interested parties, and enunciated through project statements to be incorporated in the park's Resource Management Plan. Furthermore, in recognition of the complexities involved in coordinating, developing, and implementing a Water Resources Management Plan, it is strongly recommended that a water resource professional staffed at Grand Teton National Park be the lead author. The planning process would leave the author well positioned to leverage internal and external funds and work effectively with park managers, other agencies, and local interests to implement recommended projects.

REFERENCES

Albright, J., 1993, Hydrologist's Summary; Use of Water Rights to Protect Park Resources, Lower Gros Ventre River Area, Grand Teton National Park: National Park Service, Water Resources Division, Fort Collins, Colorado, 13 pp.

Albright, J., 1997, personal communication: Hydrologist, Water Rights Branch, Water Resources Division, National Park Service, Fort Collins, Colorado.

Anderson, R., 1997, personal communication: Team Leader, U.S. Forest Service, Jackson, Wyoming.

Annear, T.C., and Bradshaw, W.H., 1992, Gros Ventre River Instream Flow Investigation, Teton County: Wyoming Game and Fish Department, Cheyenne, Wyoming, 16 pp.

Annear, T.C., 1997, personal communication: Instream Flow Specialist, Wyoming Game and Fish Department, Cheyenne, Wyoming.

Besson, L.M., and Fassett, G.W., 1997, Letter to Jack Neckles, Superintendent, Grand Teton National Park, from the Wyoming Water Development Commission: July 7, 1997. Cheyenne, Wyoming, 2 pp.

Brewer, C.A., 1988, Assessment of the Littoral Macrophyte Community in Jackson Lake, Grand Teton National Park, Wyoming, Following Reconstruction of the Jackson Lake Dam: University of Wyoming National Park Service Research Center, Laramie, Wyoming, Annual Report, pp. 90-95.

Campbell, T.M., and Lasley, C. L., 1990, Minimum Instream Flows for the Lower Gros Ventre River, Teton County, Wyoming: Lower Gros Ventre River Study Group, Wilson, Wyoming, 52 pp.

Clark, M.C., 1993, Assessment of Selected Constituants in Surface Water of the Upper Snake River Basin, Idaho and Western Wyoming, Water Years 1975 - 1989: U.S. Geological Survey, Water-Resources Investigtion Report 93-4229, 49 pp.

Collins, T.C., 1977, Instream Flows for Beaver Populations; Effects of a Midwinter Drawdown of the Snake River and Drought in Grand Teton National Park: University of Wyoming, Laramie, WY., 31 pp.

Cox, E.R., 1977, Preliminary Study of Wastewater Movement in and near Grand Teton National Park, Wyoming, Through October, 1976: Open file report 77-275, U.S. Geological Survey, Cheyenne, WY, 35 pp.

Cox, E.R., 1974, Water Resources of Grand Teton National Park: U. S. Geological Survey, Open-file report, 114 pp.

Crandall, H., 1982, Grand Teton - The Story Behind the Scenery: KC Publications, Las Vegas, Nevada, 46 pp.

Dunne, T., and Leopold, L.B., 1978, Water in Environmental Planning: W.H. Freeman and Co., San Francisco, California, 818 pp.

Faler, W., 1996, Grand Teton National Park Service Spill Prevention, Control and Countermeasures Plan: Lockheed Idaho Technologies Co., 42 pp.

Farag, A., Goldstein, J., and Woodward, D., 1997, The Influence of Human use on the Water Quality in the Backcountry of Grand Teton National Park: U. S. Geological Survey Midwest Science Center, Jackson Field Station, Jackson, Wyoming, 24 pp. + tables.

Farag, A., and Goldstein, J., 1998, Water Quality in the Backcountry of Grand Teton National Park: U.S. Geological Survey, Biological Resources Division, Environmental and Contaminants Research Center, Field Research Station, Jackson, Wyoming, 31 pp.

Federal Highway Administration, 1986, Parkwide Road Engineering Study, Grand Teton National Park Road System Final Report, 442 pp.

Glass, W.R., Keefer, T.N., and Rankl, J.G., 1974, Hydrologic Consequences of Hypothetical Earthquake-caused Floods from Jackson Lake, Grand Teton National Park, Wyoming: U.S. Geological Survey, preliminary draft copy, 46 pp. + Appendices.

Good, W.R., 1971, Downstream Drift of Aquatic Invertebrates in the Snake River, Grand Teton National Park: Department of Zoology and Physiology, University of Wyoming, Laramie, Wyoming, 75 pp.

Hayden, P., 1989, Memorandum to Jeff Albright, Water Resources Branch, Fort Collins, Colorado entitled "Lower Gros Ventre River Water Rights Issue." December 12, 1989. L54(GRTE). Grand Teton National Park, Moose, Wyoming, 3 pp. + tables.

Houston, D.B., and P.S. Hayden, 1969, Snake River Cutthroat Trout Investigations: National Park Service progress report, park files, 37 pp.

Huntoon, P.W., and Mills, J., 1987, Research Proposal - Hydrodynamics of an Alpine Karst in Paeleozoic Carbonates, Gros Ventre Mountains, Wyoming: Department of Geology and Geophysics, University of Wyoming, Laramie, Wyoming, 16 pp.

Huntoon, P.W., and Kuniansky, N.J., 1975, Karstic Ground Water Circulation and Potential Pollution Problems in the Paleozoic Carbonate Rocks of the Teton Range, Grand Teton National Park, Wyoming: Unpublished proposal submitted to the Yellowstone Environmental Council, 21 pp.

Irwin, R.J., 1997, Contaminants Encyclopedia: Volumes I, II, and III: National PArk Service, Water Resources Division, Water Operations Branch, Fort Collins, Colorado.

Jackson, B., and Sharrow, D., 1993, Memorandom to Mike Duwe, Rocky Mountain Region, Division of Planning and Compliance entitled “Comments on the Grand Tetons, Rockefeller MP Draft Road Material Source Plan Environmental Assessment.” November 1, 1993. L54(479) GRTE. National Park Service, Water Resources Division, Fort Collins, Colorado, 4 pp.

Kerr, R.I., 1977, Memorandum to Regional Director, Rocky Mountain Region entitled “Bureau of Reclamation Flow Reduction in the Snake River.” February 23, 1977. L54. Grand Teton National Park, Moose, Wyoming, 3 pp.

Kiefling, J.W., 1973, Habitat Evaluation of the Snake River and Tributary Streams, Part I Gros Ventre River Habitat Evaluations, Part II Snake River Harvest Evaluation: Wyoming Game and Fish Department Coop. Research Project No. 4, F-37-R-6, Cheyenne, WY, 104 pp.

Kiefling, J.W., 1978, Studies on the Ecology of the Snake River Cutthroat Trout: Fisheries Technical Bulletin No. 3, Wyoming Game and Fish Department, Cheyenne, Wyoming, 198 pp.

Kiefling, J.W., 1986, Letter to Marshall Gingery, Assistant Superintendent, Grand Teton National Park, from Kiefling, J.W., Fisheries Biologist, Fisheries Management Crew 10, State of Wyoming Game and Fish Department: Jackson, Wyoming, August 14, 1986.

Kiefling, J.W., 1997, personal communication: Regional Fisheries Supervisor, Wyoming Game and Fish Department, Jackson, Wyoming.

Kiefling, J.W., 1998, personal communication: Regional Fisheries Supervisor, Wyoming Game and Fish Department, Jackson, Wyoming.

Kroger, R.L., 1967, A Study of the Classification and Ecology of the Aquatic Invertebrates in the Snake River, Grand Teton National Park: Unpublished M.S. Thesis, University of Wyoming, Laramie, 161 pp.

Long, B.A., Jackson, W.L., Rosenlieb, G.W., and Walker, W.H., 1997, Review of the National Water Quality Assessment (NAWQA) Program in National Parks, Fiscal Year 1996: National Park Service, Water Resources Division, Fort Collins, Colorado, 20 pp.

Long, B.A., 1998, personal communication: Hydrologist, National Park Service, Water Resources Division, Fort Collins, Colorado.

Love J.D., and Reed, J.C. Jr., 1968, Creation of the Teton Landscape, the Geologic Story of Grand Teton National Park: Grand Teton Natural History Association, Moose, Wyoming, 120 pp.

Love, J.D., and Christiansen, A.C., 1985, compilers, Geologic Map of Grand Teton National Park, Teton County, Wyoming: U.S. Geological Survey, Miscellaneous Geologic Investigations Series Map I-2031, scale 1:62500, 1 sheet.

Maret, T.R., 1995a, Water Quality Assessment of the Upper Snake River Basin, Idaho and Western Wyoming - Summary of Aquatic Biological Data for Surface Water through 1992: U. S. Geological Survey, Water-Resources Investigation Report 95-4006, 59 pp.

Maret, T.R., 1995b, Mercury in Streambed Sediment and Aquatic Biota in the Upper Sanke River Basin, Idaho and Western Wyoming, 1992: U. S. Geological Survey, National Ambient Water Quality Assessment Fact Sheet, FS-089-95, 2 pp.

Marston, R. A., 1993, Changes in Geomorphic Processes in the Snake River Following Impoundment of Jackson Lake and Potential Changes due to 1988 Fires in the Watershed: Department of Geography and Recreation, University of Wyoming, Laramie, WY, 129 pp.

Martin, L., 1997a, personal communication: Hydrologist, Water Rights Branch, Water Resources Division, National Park Service, Fort Collins, Colorado.

Martin, L., 1997b, Memorandum to Superintendent, Grand Teton National Park, entitled "Trip Report for Travel to Grand Teton National Park on October 6-8, 1997": November 12, 1997. L54(2380). National Park Service, Water Resources Division, Fort Collins, Colorado, 6pp.

Martner, B.E., 1986, Wyoming Climate Atlas: Lincoln, University of Nebraska Press, 432 pp.

McFeters, G.A., and Stuart, S.A., 1976, Microbial Studies of a High Alpine Water Supply used for Recreation: Final report, National Park Service contract no. PX120050892, Montana State University, Bozeman, Montana, 80 pp.

Mekeel, W.L., 1972, An Interdisciplinary Overview of the Water Resources of Grand Teton National Park: Unpublished M.S. Thesis, University of Wyoming, Laramie, Wyoming, 86 pp.

Meier, P. and D. Travers, 1996, The Effects of Ungulate Grazing on Stream Ecosystems with Emphasis on the Macroinvertebrates in the Grand Teton National Park, WY.

Miller, W., and Bellini, 1996, Trophic State Evaluation of Selected Lakes in Grand Teton National Park: University of Wyoming, National Park Service Research Station, Laramie, Wyoming, 111 pp.

Miller, W., and Dustin, S., 1997, Continuation of the Trophic State Evaluation of Selected Lakes in Grand Teton National Park: Brigham Young University, Provo, Utah, 78 pp.

Mills, J.D., 1991, Wyoming's Jackson Lake Dam, Horizonatal Channel Stability, and Floodplain Vegetation Dynamics: Masters thesis, University of Wyoming, Laramie, Wyoming, 54 pp.

Mullen, K.T., 1997, personal communication: Management Assistant, National Park Service, Grand Teton National Park, Moose, Wyoming.

National Park Serivce, 1976, Jackson Hole Land-Use Study: Grand Teton National Park, Moose, Wyoming, 34 pp.

National Park Service, 1986, Natural Resources Management Plan and Environmental Assessment for Grand Teton National Park: National Park Service, Grand Teton National Park, Moose, WY, 459 pp.

National Park Service, 1988, Ammendment to Environmental Assessment, Rehabilitation of East Side Highway, Segment C, Package # 328-C: Grand Teton National Park, GRTE-EA-003-1988, Teton County, WY.

National Park Service, 1993, Floodplain Management Guideline: United States Department of the Interior, 14 pp.

National Park Service, 1995, Statement for Management: Grand Teton National Park, Moose, Wyoming, 37 pp.

National Park Service and U. S. Geological Survey, 1995, Inter-agency Agreement Between U.S. Geological Survey and the National Park Service: IA 1460-5-0005, 3 pp.

National Park Service, 1997a, Snake River Management Plan/Environmental Assessment: Grand Teton National Park, Moose, Wyoming, 76 pp. + Appendices.

National Park Service, 1997b, Environmental Assessment, Rehabilitate U.S. Highway 26/89/191/287, Develop Spread Creek Material Source and Staging Area: Grand Teton National Park, Moose, Wyoming, 75 pp.

Noland, B.T., and Miller, K.A., 1995, Water Resources of Teton County, Wyoming, Exclusive of Yellowstone National Park: U. S. Geological Survey, Water Resources Investigation Report 95-4204, 76 pp.

Pettee, C. W., 1997, Personal Communication: Acting Chief, Water Rights Branch, Water Resources Division, National Park Service, Fort Collins, Colorado.

Petts, G.E., 1979, Complex Response of River Channel Morphology to Reservoir Construction: Progress in Physical Geography, vol. 3, p. 329-362.

Rollefson, M.D., and J. Erickson, 1972, Bypass at Jackson Lake Dam: Wyoming Game and Fish Department Administrative Report 0170-0807004, 22 pp.

Rosenlieb, G., 1997a, Memorandum to Superintendent, Yellowstone National Park, entitled "Trip Report for Travel to Cheyenne, WY to attend Wyoming Total Maximum Daily Load Planning Session": April 9, 1997. L54(2380). National Park Service, Water Resources Division, 7 pp.

Rosenlieb, G., 1997b, Memorandum to Superintendent, Yellowstone National Park, Grand Teton National Park, and Bighorn Canyon National Recreation Area entitled "Trip Report for Travel to Casper, Wyoming to Attend Wyoming Department of Environmental Quality Total Maximum Daily Load Advisory Council Meeting, October 9 to 10, 1997": October 16, 1997. L54(2380). National Park Service, Water Resources Division, 3 pp.

Rosgen, D., 1996, Applied River Morphology: Wildland Hydrology, Pagosa Springs, Colorado

Rowan, D.E., 1992, Snake River Cutthroat Trout Spawning Inventory of Tributaries to the Snake River (Jackson Lake to Palisades Reservoir), Wyoming, USA: Trout Unlimited (Jackson Hole Chapter), Jackson, Wyoming,

Schiller, R., 1997, Personal Communication: Chief, Science and Resource Management Division, Grand Teton National Park, Moose, Wyoming.

Skinner, M.M., 1977, Sedimentation Problems on the Buffalo Fork River, Gros Ventre River, Spread Creek, and Pilgrim Creek: Contract Report for Teton County 208 Planning Agency, Civil Engineering Department, Colorado State University, Fort Collins, CO.

Smillie, G., 1991, Memorandum to Pam Matthes, Water Resources Program Coordinator entitled "Review of Statement of Findings for use of Floodplains in Grand Teton National Park." January 25, 1991. L54(479). National Park Service, Water Resources Division, Fort Collins, Colorado, 1 pp.

Smillie, 1997, Personal Communication: Hydrologist, National Park Service, Water Resources Division, Fort Collins, Colorado.

Smillie, G., and Keough, D., 1997, Memorandum to Rande Simon, Roads and Trails Facility Manager, Grand Teton National Park entitled "Field Investigation - Review of Boat Landing Sites": No date or file code, National Park Service, Water Resources Division, Fort Collins, Colorado, 6 pp.

Smith, M.A., Dodd, J.L., and Meiman, P.J., 1993, Effects of Domestic Livestock and Native Wildlife Grazing in Grand Teton National Park, Semiannual Report: Range Management Department, University of Wyoming, Laramie, Wyoming, 9pp.

Smith, M.A., J.L. Dodd, and P. Meiman, 1994, unpublished, Effects of Domestic Livestock and Wildlife Grazing in Grand Teton National Park, University of Wyoming, Laramie, Wyoming.

Stockdale R.G., 1995, Water-Right Administration: *in* Noland, B.T., and Miller, K.A., 1995, Water Resources of Teton County, Wyoming, Exclusive of Yellowstone National Park: U. S. Geological Survey, Water Resources Investigation Report 95-4204, 76 pp.

U.S. Army Corps of Engineers, 1989, Jackson Hole Wyoming Flood Protection Project, draft O&M Decision Document and EIS: Walla Walla District, Walla Walla, Washington, 148 pp.

U.S. Army Corps of Engineers, 1992, Recent Erosion Processes and Trends Affecting the Snake River Channel Within and Downstream of the Federal levee Project: Walla Walla District, Hydrology Branch, Walla Walla, Washington, 14 pp. + Plates.

U.S. Bureau of Reclamation and National Park Service, 1984, Draft Environmental Impact Statement; Jackson Lake Safety of Dams Project: DEIS 84-34, Boise, Idaho and Denver, Colorado.

U.S. Department of Agriculture, 1982, Snake River - Wyoming, A Potential Wild and Scenic River - Final Statement and Report: USDA, Washington, D.C., 150 pp + Appendices.

U.S. Fish and Wildlife Service, 1995, Memorandum to Superintendent, Grand Teton National Park entitled "Listed, Proposed, and Candidate Threatened or Endangered Species in Accordance with Section 7(c) of the Endangered Species act of 1973", 2 pp.

U.S. Forest Service, 1997, Scoping Statement, Oil and Gas Leasing within Management Areas 21, 45, 71, and 72; Big Piney Ranger District, Jackson Ranger District, Pinedale Ranger District, Bridger-Teton National Forest: U.S. Forest Service, Bridger-Teton National Forest, Jackson, Wyoming, 8 pp.

Wagner, J., and Martin, L., 1996, Memorandum to Superintendent, GRTE, entitled "Report for Travel to Grand Teton National Park and John D. Rockefeller Jr. Memorial Parkway on Sept. 3-6, 1996." October 7, 1996. L54(2380). National Park Service, Water Resources Division, Fort Collins, Colorado, 13 pp.

Williams, G.P. and Woolman, M.G., 1984, Downstream Effects of Dams on Alluvial Rivers: U.S. Geological Survey Professional Paper1286, Reston, Virginia.

Woodin, R., 1977, Low Flow was no Low Blow: Article in the Jackson Hole Guide, Nov. 10, 1 pp.

Wolman, M.G., and Miller, J.P., 1960, Magnitude and Frequency of Forces in Geomorphic Processes: Journal of Geology, vol. 68, p. 54 – 74.

Wyoming Department of Environmental Quality, 1996, Wyoming Water Quality Assessment: Wyoming Department of Environmental Quality, Water Quality Division, Cheyenne, Wyoming, 323 pp.

Wyoming Game and Fish Department, 1997, Fisheries Management Crew 10; Draft of Proposed Restoration Project - Upper Bar BC Spring Creek, *in* National Park Service, 1997a, Snake River Management Plan/Environmental Assessment: Grand Teton National Park, Moose, Wyoming, 76 pp. + Appendices.

Wyoming Game and Fish Department, 1992, The Snake River Cutthroat Trout: Wyoming Game and Fish Department, Informative Brochure, Jackson, Wyoming.

Wyoming State Engineer's Office, 1972, Water and Related Land Resources of the Snake River Basin, Wyoming:, Wyoming State Engineer's Office., Wyoming Water Planning Program, Report # 12, Cheyenne,WY, 152 pp.

Young, H.W., D.J., Parliman, M.L. Jones, and M.A.J. Stone, 1991, Hydrologic and Water Quality Data for Selected Sites, Grand Teton National Park, Wyoming, September 1988 through September 1990.